ASSOCIATIONS AMONG SELECTED PHYSCIO-CHEMICAL PARAMETERS AND SIMULIIDAE (DIPTERA) FROM 23 LAKE-OUTLET SITES IN NEWFOUNDLAND

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Associations among selected physcio-chemical parameters and Simuliidae (Diptera) from 23 lake-outlet sites in Newfoundland

by
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ABSTRACT

The association between anthropogenic inputs, often the result of human activity within a watershed, and the structure of the simuliid community were investigated. The environmental analyses showed statistically significant regional and site differences related to the chemical stream variables, but the approach used showed no statistically significant differences in the physical stream variables, except for proximate vegetative cover and physical disturbance scores. The site differences in St. John's were attributed to urbanisation, but the site differences in the other regions could not be associated to specific environmental variables.

Simuliids were selected for study because they have a passive filter-feeding stage which is susceptible to disturbances associated with increased human activities within a watershed and natural disturbances associated with stream processes. These relationships were investigated using 21 environmental variables correlated to pooled taxa richness, pooled taxa abundance, and final-instar head capsule size using univariate and multivariate statistical methods.

The biological analyses showed no statistically significant differences in the pooled taxa richness and pooled taxa abundance per region. However, there were statistically significant site differences in the pooled taxa richness and pooled taxa

abundance. These differences were correlated to SO_4^{2-}, K^+, Zn^{2+}, and Cu^{2+} concentrations. The multivariate analyses, which statistically grouped chemical, physical, and biological variables into composite variables, showed a negative correlation between principal components Environmental Factor III (SO_4^{2-} and Cu^{2+} ion concentrations) and Presence/Absence Factor I (absence of *Simulium decorum*, *S. tuberosum*, *Eusimulium canonicolum*, *Stegopterna mutata*, and *Prosimulium mixtum/fuscum* complex). Principal component Environmental Factor III was also negatively correlated to principal component Abundance Factor I (scarcity of *P. mixtum/fuscum* complex, *Cnephia ornithophilia*, and *Simulium tuberosum*, and *Simulium vittatum*). Principal components Environmental Factor II (stream order, average velocity, substrate type, and stream width) and Environmental Factor V (physical disturbance score) were positively and negatively correlated to principal component Abundance Factor II respectively (abundance of *Simulium venustum/verecundum* complex and *E. furculatum*, and scarcity of *E. craigi/caledonense* complex). Final-larval instars of *S. vittatum* had significantly larger mean head capsules than *St. mutata* than *P. mixtum/fuscum* complex. Final-larval instars collected from sites located in the lower reaches of a watershed had smaller mean head capsules compared to final-larval instars collected from the upper reaches which were more variable in size. The pooled taxa richness, pooled taxa abundance, and final-larval instar size of simuliids were useful in detecting

environmental differences among regions and sites. However, it was difficult to distinguish among regions and sites with low-to-moderate or variable environmental conditions as in the case of Bonavista, Random Island, and Come-by-Chance.

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1.0. INTRODUCTION

1.1. The Project

This study is a segment of the broader Eco-Research programme that examined watershed health and future sustainability of selected coastal human communities in eastern Newfoundland. This programme was established in response to the North Atlantic cod fishery moratorium which has had a negative impact on the way of life in these coastal communities.

Two important environmental components related to determining sustainability of human communities are the health of the freshwater ecosystem and the impact of land-use practices on these ecosystems. This project's objective was to determine the environmental condition of 4 regions and 23 sites on the Avalon and Bonavista Peninsulas using standard chemical and physical stream variables. These variables included, but were not limited to, ground-cover loss (riparian and in the watershed), pH, conductivity, ionic concentrations, substrate type, stream order, and stream width. The aim of this research was to investigate the association between anthropogenic inputs, often the result of human activity within a watershed, and the structure of the simuliid community on the Avalon and Bonavista Peninsulas. Elements of the simuliid community examined included: taxa richness (i.e., numbers of taxa), taxa abundance (i.e., numbers of individuals), and final-larval instar size. Ultimately, data gathered in the future can be compared to the data collected by this

research to determine if human development in the four regions has had an impact on the simuliid community.

1.2. Eco-Research Programme

The Eco-Research programme is a multi-disciplinary project encompassing the Social, Health, and Natural Sciences with a mandate to identify historical elements that have contributed to the sustainability of coastal human communities on the Avalon and Bonavista Peninsulas. It is believed that answers to the current problems faced by these coastal communities may lie in their past, and therefore historical information should be included in the development of future policies regarding their sustainability (Ommer 1993).

Social scientists are interested in the effects of the moratorium on the lives of individuals and entire human communities. Is there a future in these outport communities? Will we see a greater net emigration of people from these areas as a result of the moratorium? Will the moratorium mark the end of a way of life in these outport communities?

Natural scientists are interested in the impacts of natural and human-induced environmental changes on these cold-ocean coastal ecosystems within the last 10,000 years. They recognise that the natural environment is in a state of dynamic equilibrium; evolving from one stable state to another stable state (Ommer 1993).

They are also interested in determining human effects on these systems in light of the moratorium. Is there any indication that the natural environment is being affected by increased human use as the human communities look for other sources of income and subsistence (e.g., tree harvesting, berry harvesting, and increased human activity in the watershed)? Is the collapse of the cod fishery an indication of the overall declining health of the natural environment in these areas? Are there other chemical and/or biological indicators, particularly in the freshwater environment, that support the declining health hypothesis?

1.3. Newfoundland's Freshwater Environment

The recent glacial history of Newfoundland resulted in watersheds that deviate from the classic graded stream profile as predicted by the River Continuum Concept (RCC) (Vannote *et al.* 1980, Larson and Colbo 1983). The island's glacial fluvial morphology consists of poorly developed drainage systems with numerous wetlands and lakes as a result of the low relief and irregular topography. These bodies of standing water act as sinks and sources for the adjoining stream systems and disrupt the continuous drainage flow pattern described by the RCC. This glacial fluvial morphology is similar to watersheds in northern Saskatchewan examined by Ciborowski and Adler (1990) in their study of the ecological segregation of larval simuliids.

Newfoundland watersheds differ however from other continental boreal-forest-dominated catchments because of the bedrock and their proximity to the Labrador current (Larson and Colbo 1983). The bedrock is composed primarily of acid or very resistant rock with very few base ions; hence, the observed poor buffering capacity of most lakes and streams in Newfoundland. Consequently, the streams are naturally acidic with low levels of dissolved materials, have low conductance, and low nutrient concentrations. Furthermore, the Labrador current creates a coastal maritime climate with cool summers, high precipitation, fog, and windy conditions. These less-than-ideal chemical and physical characteristics create harsh if not hostile environments for aquatic insects.

1.4. Simuliid Natural History

Newfoundland's aquatic insect fauna has low diversity consisting of many generalist species with wide geographic ranges and presumably high dispersal capabilities (Larson and Colbo 1983). The island's simuliid assemblage is impoverished with only 5 genera and 23 species identified at present. Many of the 23 species are complexes of sibling species or cytotypes which are morphologically similar but genetically distinct taxa. However, even with this cytological knowledge, the number of simuliid species in Newfoundland is still quite low relative to the numbers from continental North America where 300 species have been identified

(Larson and Colbo 1983, McCreadie *et al.* 1995). Specific details about the simuliid community of Newfoundland (i.e., what species and their habitat requirements) are included in the Discussion section.

By way of a general natural history description, simuliids are true flies belonging to the Order:Diptera, Family:Simuliidae. They are holometabolous benthic macroinvertebrates that can have as many as 11 instars (Colbo 1989, Crosskey 1990). They are passive, non-selective filter-feeding organisms that rely on the water current to transport seston that they capture with their cephalic fans; two genera (i.e., *Twinnia* and *Gymnopais*) lack cephalic fans and feed by scraping particles off the substrate surfaces. They exhibit seasonality in their development which can either be univoltine (i.e., a single generation in a single season), bivoltine (i.e., two generations), or multivoltine (i.e., several generations). They are early colonisers of disturbed sites because they require smooth, algal-free, stable substrates for attachment with their anal hooks (Kurtak 1978, Wallace and Merritt 1980, Merritt *et al.* 1982, Craig and Galloway 1987, Currie and Craig 1987, Kim and Merritt 1987, Ross and Merritt 1987, Morin and Peters 1988, Crosskey 1990).

Simuliids are prevalent in small- to medium-sized lake-outlet streams. Aggregations greater than 10^6 individuals per square metre have been reported in the first few metres downstream of an outlet stream in England (Wotton 1984). This high aggregation is due in part to the larval diet which consists of fine particulate

organic matter (FPOM) from autochthonous and allochthonous sources. Autochthonous sources within a stream include the break down of coarse particulate organic matter (CPOM) by other macroinvertebrates and the release of fæces, abrasion of CPOM by sediments in transport, decaying macrophytes, scouring of algal cells from the substrate, and flocculation of dissolved organic matter (DOM) by physical-chemical processes (Carlsson *et al.* 1977, Wallace and Merritt 1980, Kim and Merritt 1987, Ross and Merritt 1987). Autochthonous sources include bacterioplankton, small phytoplankton, zooplankton, and detritus. Allochthonous FPOM can enter the stream through wind blow, surface runoff, bank erosion, and/or from rain dripping through the forest canopy (Wallace and Merritt 1980, Kim and Merritt 1987, Ross and Merritt 1987).

Simuliid abundance has been shown to decrease exponentially downstream from lake outlets because of the shift from high-quality seston at the mouth of the outlet to refractory inorganic and mineral particles downstream (Amrine 1982, Bass and Armitage 1987, Morin and Peters 1988, Richardson and Mackay 1991). Colbo and Porter (1979) showed that reduced seston concentrations and quality resulted in longer developmental times, declining survival, and decreased adult size and fecundity of simuliids. Perez (*unpublished data*; experiment conducted at the University of Toronto using specimens collected from an outlet draining into the Rouge River Valley) showed that increasing concentrations of suspended clay

particles resulted in smaller final-instar *Prosimulium mixtum/fuscum* complex (Syme and Davies) larvae under experimental conditions. The smaller larval size was attributed to a decrease in the quality of the seston due to dilution by the suspended clay particles.

Other factors influencing simuliid richness and abundance include: 1) eutrophication of the watershed and the associated algal bloom as a result of the fertilisation of the riparian zone, 2) riparian cover differences, 3) levels of human disturbance and development (e.g., channelisation and dredging of the outlet stream), 4) limnological factors (e.g., pH, conductivity, selected ion concentrations), 5) physical stream characteristics (e.g., stream width, depth, current velocity), and 6) life-history patterns and adult female ovipositing behaviours (Lake and Burger 1983, Ross and Merritt 1987, Morin and Peters 1988, Ciborowski and Adler 1990, Crosskey 1990, McCreadie and Colbo 1992, Colbo 1993, Hall 1994).

1.5. Biomonitoring and Benthic Macroinvertebrates

The use of benthic macroinvertebrates as bioindicators of anthropogenic stress is widely accepted because the responses of many species to different environmental conditions are known and body burdens of chemical compounds tend to reflect local conditions (Beckett and Keyes 1983, Basaguren and Orive 1990, Cain *et al.* 1992, Harding 1992, Johnson *et al.* 1993, Resh and Jackson 1993, Rosenberg

and Resh 1993, Hall 1994, Vuori 1995). However, Barton (1989) cautions against blindly using benthos to assess anthropogenic inputs because the absence of a taxa might be related to life histories and sampling protocols rather than sediment toxicity effects. Furthermore, short-term chemical and physical stressors (e.g., chlorine, pH changes associated with snow melt, and temperature) can eliminate taxa without leaving toxic residues in the sediments. Johnson *et al.* (1993) paraphrased Barton (1989) when they stated that "the presence of a species assures us that a certain minimum condition has been met; the absence of a species, however, does not tell us that the minimum condition has not been met". Therefore, a combination of chemical and physical measurements as well as a biological criteria using benthos is required to fully assess the environmental state of a stream.

Simuliids are "ideal sentinel organisms" because they are relatively sedentary, easy to collect, able to withstand field and laboratory handling, and are sensitive to a range of environmental conditions (Colbo 1979, Hall *et al.* 1980, McCreadie 1991, Johnson *et al.* 1993, Hall 1994). Taxa richness, abundance, and final-instar sclerite size (head capsule measurements) are predicted to decrease in response to a substantial increase in anthropogenic inputs. Morin and Peters (1988) showed a negative correlation between biomass of *P. mixtum/fuscum* and *Stegopterna mutata* (Malloch) and periphyton standing crops. This decrease in biomass is attributable to the larvae not being able to anchor themselves with their anal hooks to the

substrate because of the dense algal growths covering the substrates. In another study, the distributions of *Cnephia ornithophilia* (Davies, Peterson, and Wood), *Simulium vittatum* (Zetterstedt), and *St. mutata* were restricted to first-to-second order streams whereas *P. mixtum* was widely distributed in first-to-fourth order streams (Colbo 1979). Colbo (1979) also reported that the amount of tree cover affected the occurrence of *C. ornithophilia* and *St. mutata*. He showed that *C. ornithophilia* was prevalent in forested areas whereas *St. mutata* was prevalent in open-barren areas.

Decreasing food quality and quantity and decreasing rearing temperatures are three other important environmental variables that have been previously studied. Colbo and Porter (1979, 1981) showed that adult size decreased with a reduction in food concentrations as did the fecundity of females in *S. verecundum* complex and *S. vittatum*. Furthermore, only larger simuliids in their study contributed significantly to the next generation of *S. vittatum*. Variability in adult simuliid size and fecundity measures collected from a series of sites within a few kilometres of each other were attributed to differences in food supply (Colbo 1982). These observations led Colbo (1982) to propose that adult size could be used as an indicator of environmental stress because it would be sensitive to environmental influences and serve as a measure of sub-lethal effects.

Ross and Merritt (1987) reported that the reduced adult size and reduced fecundity resulted from larvae growing and developing in sub-optimal conditions

which ultimately limited a species' distribution by reducing its competitive advantage in dispersing over wide geographic regions. Honěk (1993) argued that "the impact of body size on fecundity cannot be denied because variation in body size may be part of a species adaptive strategy, particularly if the variation has a potential in minimising intraspecific competition for a limited resource".

The problem with collecting emerging adults is the associated logistical difficulties and expense if one's study encompasses a large geographic region. The primary problem is the narrow emergence temporal window and the large geographic distances to be travelled to reach all the sites while the adult flies are emerging. It is more feasible to collect final-larval instars because of the longer availability period (i.e., weeks instead of days). Furthermore, environmental effects that manifest in adult size should first appear in the earlier stages, particularly in the final-larval instar stage. This final point has not yet been experimentally quantified.

From the above examples, simuliids may prove useful indicators of human impacts on the stream environment. Correlation and principal components analyses were used to determine associations between anthropogenic abiotic inputs, often the result of human activity within a watershed, and the structure of the simuliid biotic community on the Avalon and Bonavista Peninsulas. Prior to the above analyses, the abiotic data (i.e., chemical and physical characteristics) from 23 lake-outlet sites were collected over a two-year period and statistically tested for significant regional

and site differences. The biotic data (i.e., taxa richness and taxa abundance), which in the context of the current research were measures of simuliid community structure, were also statistically tested for significant regional and site differences.

2.0. MATERIAL AND METHODS

This study had abiotic (environmental) and biotic (biological) components. The abiotic component consisted of chemical and physical stream variables. The chemical data were measured in late May and late July, for two years beginning in May 1995 and ending in May 1997. These sample periods coincided with the collections of the simuliid specimens. The physical data were measured only once as they were not expected to dramatically change over the relatively short duration of the study. The biotic data consisted of simuliid taxa richness, taxa abundance, and final-instar size measurements collected using qualitative sweeps and artificial substrates beginning in July 1995 and ending in May 1997. The analyses of the abiotic and biotic data involved univariate and multivariate techniques from two statistical packages.

2.1. Environmental Variables

2.1.1. *Twenty-three sites from four regions*

Newfoundland's boreal landscape consists of barren areas with dwarf-scrub heaths, bogs, and shallow fens, and forested areas dominated by *Abies balsamea* (balsam fir) and *Picea mariana* (black spruce). Other common tree species include *Acer rubrum* (red maple), *Alnus crispa* (mountain alder), *Betula papyrifera* (white birch), *Picea glauca* (white spruce), and *Pinus strobus* (white pine) (Lomond 1997).

Sweetgale or bog-myrtle (*Myrica gale*) and meadowsweet (*Spiræa latifolia*) are the prevalent bank side vegetation. Meadow-rue (*Thalictrum polygamum*) is a prevalent herb, and several species of sedges and grasses occur in the four regions (P. Scott, *personal communication*). The four regions selected in this study represent similar aspects of Newfoundland's geological and limnological character as described in Larson and Colbo (1983).

Within the 4 regions, 16 lake-outlet sites were sampled beginning in May 1995 (Table 1, Figure 1). The Bonavista, Random Island, and Come-by-Chance sites were selected because they represented a range of environmental conditions (i.e., similar sized outlets, similar levels of human activity from no activity to roads, similar canopy cover and concentrations of ions, etc.) that may have some impact on the simuliid assemblage occurring at these sites. They were also selected because they were areas of interest to other researchers involved in the Eco-Research programme.

Seven sites were selected from Bonavista (Table 1, Figure 2). B1 is the outlet stream of Beaver/Hospital Pond and is located in the centre of Bonavista. It was formerly used as a refuse pond by the hospital. B2 is the outlet stream of Long Pond and is the water supply for the Town of Bonavista. There is a pump house located several metres downstream of the outlet. An old concrete foot bridge and signs of beaver activity were noted in B3. The short outlet stream is also

Table 1. Location of 23 lake-outlet sites on the Avalon and Bonavista Peninsulas of Newfoundland. Seven sites are in or near the Town of Bonavista on the Bonavista Peninsula. Five sites are on Random Island near Hickman's Harbour flowing into the northwest arm of Random Sound. Four sites are near the Towns of Come-by-Chance and Sunnyside at the head of Bull Arm on the Isthmus of theAvalon Peninsula. Seven sites are in the Cities of Mount Pearl and St. John's and the Town of Paradise.

Site designation (local names)	Latitude and Longitude (degree/minute)	General description of sites and activity at the outlets
Bonavista		
B1 (Beaver/Hospital Pond)	48°39' N 53°06' W	Situated in the centre of Bonavista, former hospital refuse pond
B2 (Long Pond)	48°37' N 53°06' W	Town water supply with water pump at the outlet, no canopy cover
B3	48°36' N 53°06' W	Beaver activity, channelised, scrubs on banks, old bridge
B6	48°37' N 53°06' W	Old railway bridge, loose fine gravel substrate, exposed
B7	48°36' N 53°06' W	Borrow pit near the outlet, exposed
B8 (Beaver Pond)	48°36' N 53°06' W	Beaver activity, near road
B18	48°37' N 53°07' W	Camping activity upstream of outlet, old beaver dam, exposed
Random Island		
R9 (Long Pond)	48°06' N 53°47' W	Road ditch outlet, no canopy cover, nearby trees
R10 (Birchy Pond)	48°08' N 53°44' W	Loose gravel, ATV trail, adjacent dairy farm, dense canopy cover
R11 (Beaver Pond)	48°07' N 53°45' W	Beaver activity, dense canopy cover, near road
R13 (Tween Bridge Pond)	48°07' N 53°45' W	Culverted site with an adjacent cemetery and a gravel road
R19 (Little Deans Cove Pond)	48°07' N 53°44' W	Dense canopy cover, near houses, old dock at outlet

Table 1. (Continued)

Come-by-Chance		
C14	47°50' N 53°57' W	Wetland, exposed, down wind of an oil refinery
C15 (Middle Pond)	47°50' N 53°56' W	Wetland, exposed, down wind of an oil refinery
C16 (Lower Pond)	47°50' N 53°56' W	Wetland, down wind of an oil refinery, overhead hydro power lines
C17 (Upper Pond)	47°50' N 53°57' W	Wetland, nearby a stand of scrubs, down wind of an oil refinery
Mt. Pearl, St. John's, and Paradise		
S20 (Brazil Pond)	47°32' N 52°50' W	Adjacent to a farmer's field, moderate canopy cover
S21 (Power Pond)	47°31' N 52°49' W	Channelised outlet without a dense canopy cover
S22 (Branscombes Pond)	47°31' N 52°47' W	Channelised outlet, a dense canopy cover, behind Sobey's Square
S23 (Long Pond)	47°34' N 52°43' W	Surrounded by three major city roads without a canopy cover
S24 (Kents Pond)	47°35' N 52°43' W	Surrounded by major city with a dense canopy cover
S25 (Virginia Lake)	47°36' N 52°42' W	Adjacent to the Virginia Lake housing sub-division
S26 (Georges Pond)	47°34' N 52°41' W	Generally exposed but with some canopy cover over the outlet

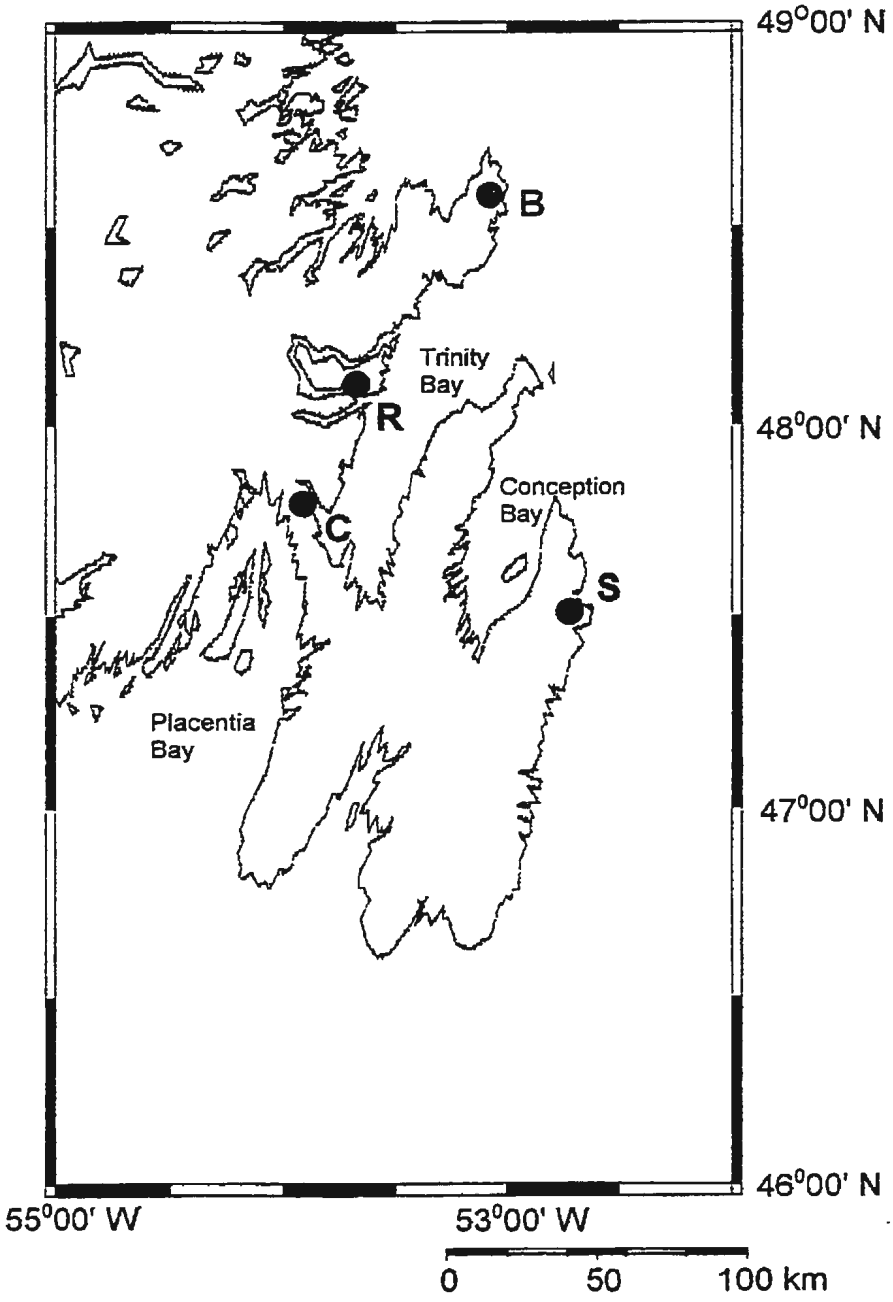


Figure 1. Location of the four regions on the Avalon and Bonavista Peninsulas of Newfoundland (i.e., B = Bonavista, **R** = Random Island, **C** = Come-by-Chance, and **S** = St. John's).

Figure 2. Location of the seven sites in Bonavista, Newfoundland (48°36' N 53°06' W to 48°39' N 53°07' W). Sites from a single catchment area were selected for this study. Major highways and the old railway were included on the map.

channelised and scrubs cover the stream banks. B6 is bisected by an old wooden railway bridge and the stream bed consisted of loose fine gravel. There was also very little vegetative cover over this outlet stream. B7 is near a borrow pit and has very little vegetative cover over the stream. B8 is near the Trans-Canada highway and has extensive vegetative cover over and near the stream. There were also signs of beaver activity in this stream. B18 is exposed with very little vegetative cover over the stream. There is an old beaver dam at the mouth of the outlet and this outlet is near a gravel-pit camp sight.

Five sites were selected from Random Island (Table 1, Figure 3). R9 is the road ditch outlet stream of Long Pond. It has no canopy cover, but is proximate to a stand of coniferous trees. R10 is the outlet stream of Birchy Pond. This stream is characterised by loose gravel substrate, an all-terrain vehicle trail bisecting the outlet, and proximate to a dairy farm. R11 is the outlet stream of Beaver Pond. This stream is near the major road through Random Island, has dense canopy cover consisting mostly of alder, and the pond is inhabited by beavers. R13 is the outlet stream of Tween Bridge Pond. Two large culverts drain Tween Bridge Pond and a Salvation Army cemetery lies on the opposite bank of the outlet stream. R19 is the outlet stream of Little Deans Cove Pond. There is an old dock at the outlet, dense canopy cover, and near several houses.

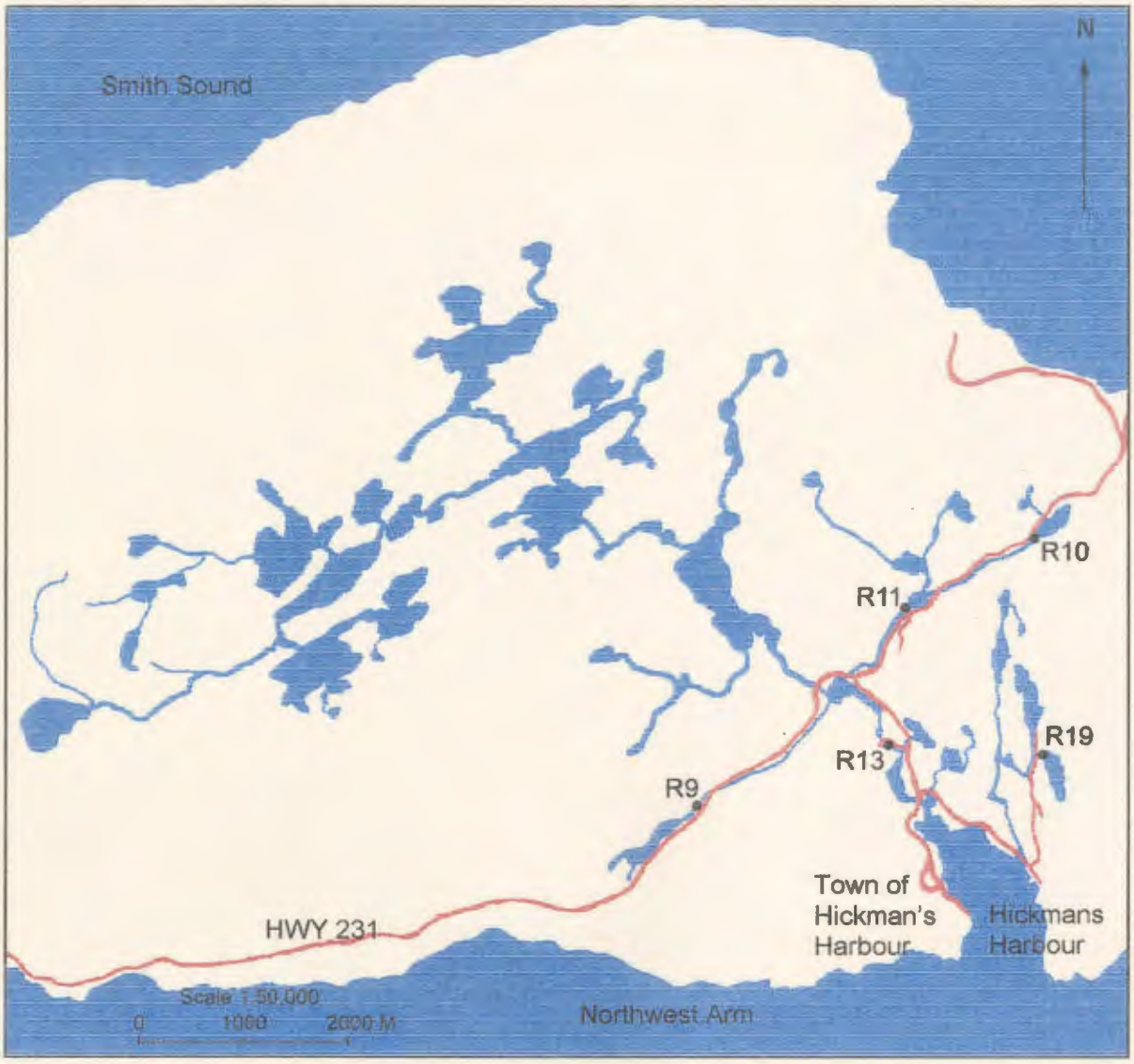


Figure 3. Location of five sites on Random Island, near Hickman's Harbour (48°06' N 53°44' W to 48°08' N 53°47' W). Sites from two catchment areas were selected for this study. The major highway was included on the map.

Four sites were selected from Come-by-Chance (Table 1, Figure 4). The four sites are in wetlands, relatively exposed with no canopy cover over the streams, and is down wind of the oil refinery with a reputation of being the "dirtiest" in Canada (M. H. Colbo, *personal communication*). Hydro electric power lines also cross near the outlet stream at C16.

The seven urbanised St. John's sites were added in May 1996 as an out-group to compare the other sites to in order to determine if highly urbanised sites had different assemblages of simuliids (Table 1, Figure 5). S20 is the outlet stream of Brazil Pond. There is moderate cover over the stream and is near a farm field. S21 is the channelised outlet stream of Power Pond. This stream is exposed with no canopy cover. S22 is the channelised outlet stream of Branscombes Pond. There is a dense canopy cover of conifers over the stream and is behind Sobey's Square supermarket. S23 is the outlet stream of Long Pond. It is an exposed stream with no canopy cover and two major city roads bisect this stream. S24 is the outlet stream of MENTS Pond. It has a dense canopy of conifers and is channelised. S25 is the outlet stream of Virginia Lake. The Virginia Lake housing development backs into this lake. S26 is the outlet stream of Georges Pond on Signal Hill. It was a former water source for the City of St. John's. This stream is generally exposed except in a few areas of dense canopy cover.

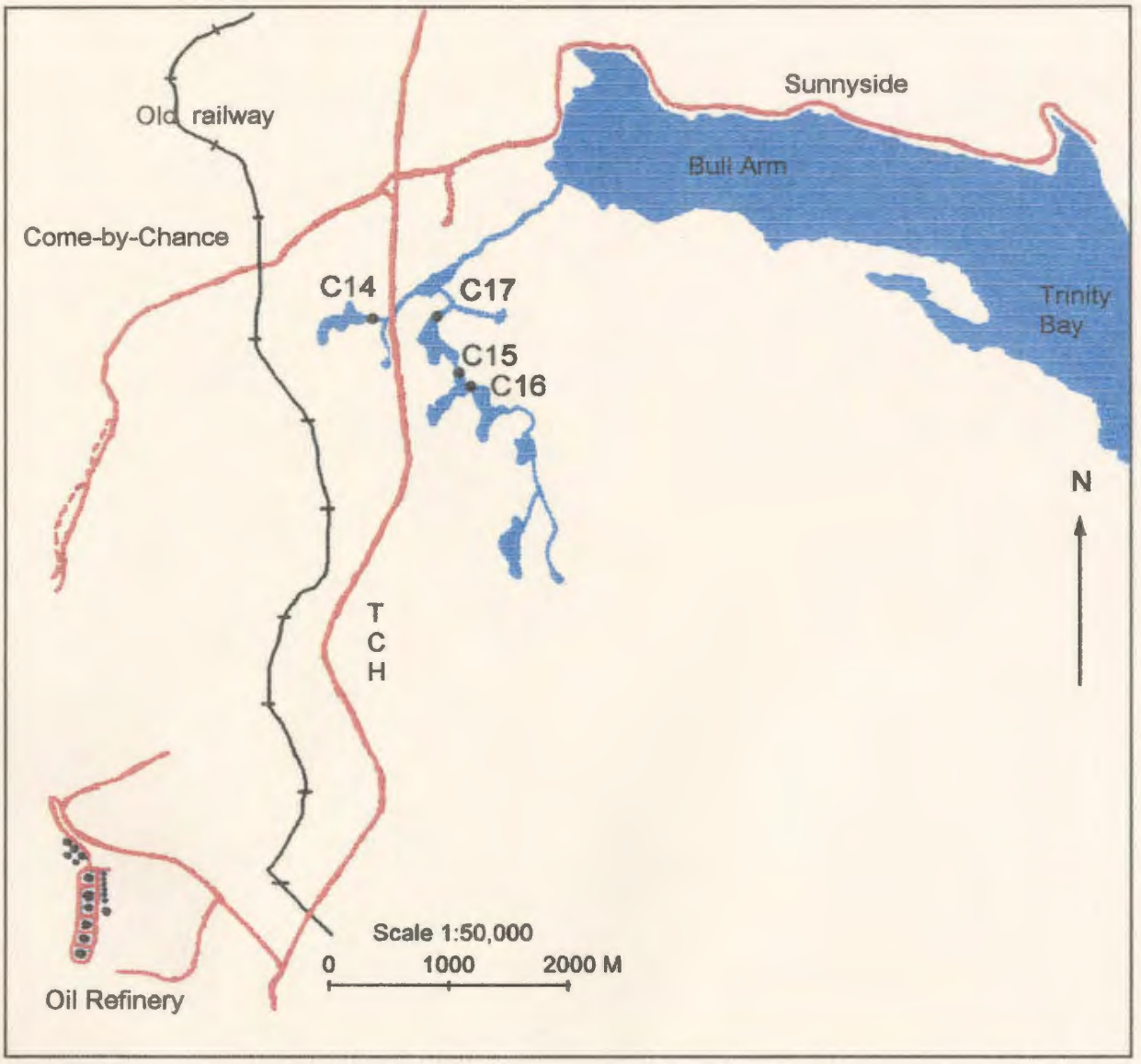


Figure 4. Location of the four sites near the Towns of Come-by-Chance and Sunnyside at the head of Bull Arm on the Isthmus of the Avalon (47°50' N 53°56' W to 47°50' N 53°57' W). Sites from a single catchment area were selected for this study. Major highways, the old railway, and the oil refinery were included on the map.

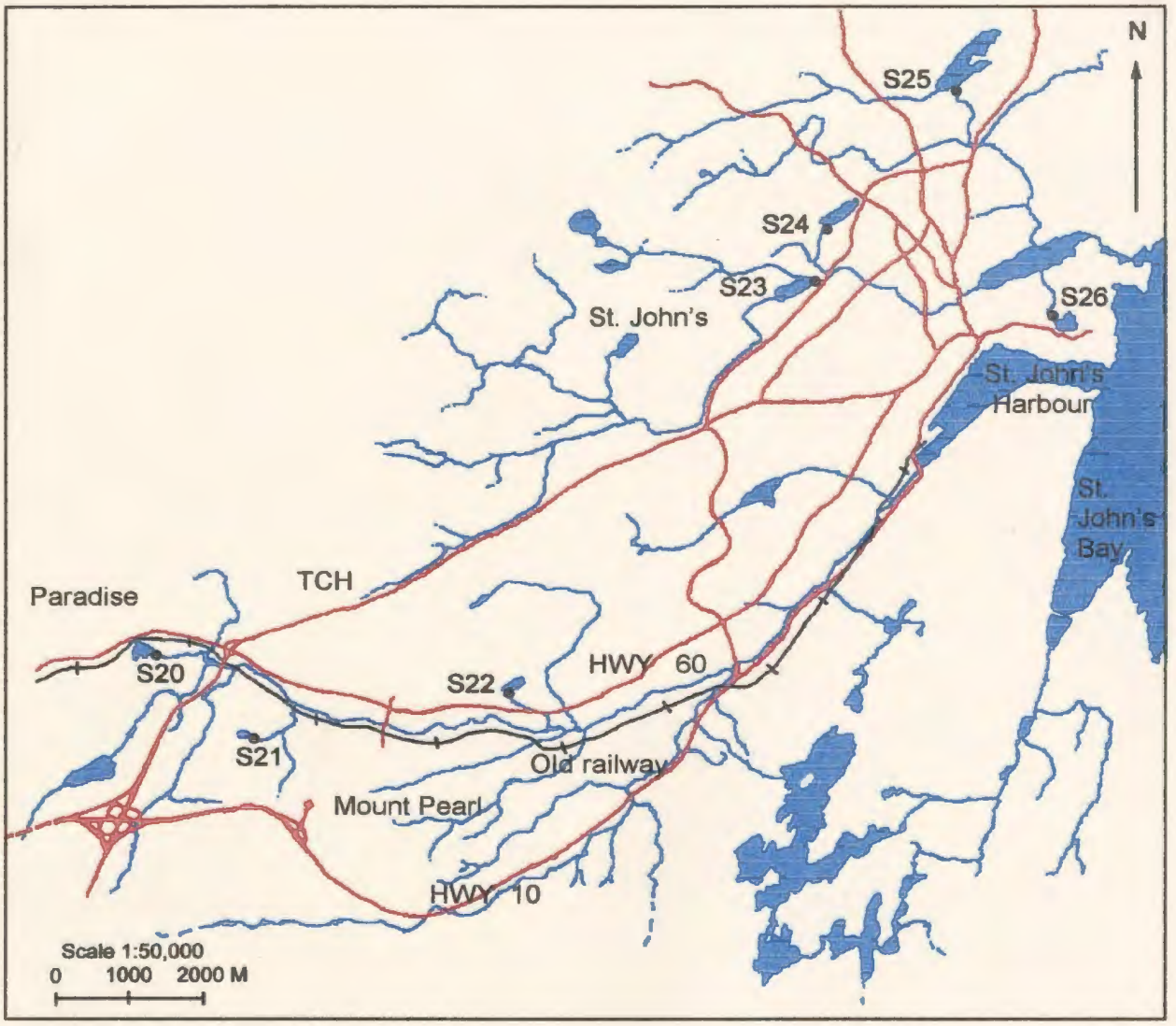


Figure 5. Location of the seven sites in the St. John's area of Newfoundland (47°31' N 52°41' W to 47°36' N 52°50' W). Sites from three catchment areas were selected for this study. Major highways and the old railway were included on the map.

2.1.2. *Chemical and physical stream variables*

The 21 environmental variables, consisting of 12 chemical and 9 physical stream characteristics, were selected on the basis of their reported impacts on simuliid taxa richness, taxa abundance, and adult size (Colbo and Porter 1979, 1981, Amrine 1982, Colbo 1982, Armitage 1984, Corkum and Currie 1987, Ross and Merritt 1987, Morin and Peters 1988, Ciborowski and Adler 1990, Crosskey 1990, McCreadie and Colbo 1991, Chmielewski and Hall 1992, Heliövaara and Väisänen 1993, Hall 1994, McCreadie *et al.* 1995).

The 12 chemical variables were measured using established sampling protocols (Table 2). *In-situ* readings of pH and conductivity were measured using two meters, an Orion Model 290A for pH and an Orion Model 122 for conductivity. Replicate water samples (two 50 mL narrow-neck plastic bottles) were taken at each site starting in May 1995 and ending in July 1996. The chemical component of the water samples were determined by mass spectroscopy, which was conducted by Dr. Peter Davenport from the Newfoundland Department of Mines and Energy. Eight ions (i.e., SO_4^{2-}, Mg^{2+}, Zn^{2+}, Al^{3+}, Ca^{2+}, K^{+}, Na^{+}, and Cu^{2+}) were selected from a list of 25 ions generated by the mass spectroscopy analyses. These eight ions were selected because of their reported effects on taxa richness, abundance, and diversity (Hall *et al.* 1980, Corkum and Currie 1987, Ciborowski and Adler 1990, Hall 1994).

Table 2. Twenty-one chemical and physical environmental stream characteristics of 23 sites on the Avalon and Bonavista Peninsulas. Vicinity of roadways and houses/buildings were measured from topographic maps and then categorised as very far (1), intermediate (2), and very close (3). Other physical characteristics are scored as indicated in the Notes column.

Chemical characteristics	Column abbreviations	Units	Type of data	Notes
pH			continuous	measured using an Orion Model 290A meter
Conductivity		µS/cm	continuous	measured using an Orion Model 122 meter
Sulphate anion	SO_4^{2-}	(mg/L)	continuous	
Magnesium cation	Mg^{2+}	(mg/L)	continuous	
Zinc cation	Zn^{2+}	(µg/L)	continuous	
Aluminum cation	Al^{3+}	(µg/L)	continuous	
Calcium cation	Ca^{2+}	(mg/L)	continuous	
Potasium cation	K^{+}	(mg/L)	continuous	
Sodium cation	Na^{+}	(mg/L)	continuous	
Copper cation	Cu	(µg/L)	continuous	
Total inorganic solids	TIS	(µg/mL)	continuous	
Total organic solids	TOS	(µg/mL)	continuous	

Table 2. (Continued)

Physcial characteristics	Column abbreviations	Type of data	Notes
Average current velocity	Avvel	continuous	measured using an A. Ott Kemptem current meter; averaged across the sampling dates
Immediate cover	Immcov	interval	vegetation hanging over and within 2 m of the stream; open (1), semi-covered (2), covered (3)
Proximate cover	Procov	interval	vegetation visible beyond 2 m of the stream; open (1), scrub-forest (2), forest (3)
Aquatic vegetation	Aqveg	interval	vascular vegetation growth in the stream; sparse (1), intermediate (2), dense (3)
Substrate	Subst	interval	modified from McCreadie (1991); mud (1), small gravel (2), wood (3), cobble (4), boulder (5)

Table 2. (Continued)

Physcial characteristics	Column abbreviations	Type of data	Notes
Stream order	Order	interval	determined using topographic maps with 1:50,000 scale; first (1), second (2), third (3), fourth (4) order streams
Stream width	Width	continuous	measured using a meter stick at widest point; averaged across 3 1-m transects
Upstream pond area	Pond area	continuous	measured using a polar planimeter and blue-line survey maps (1:1,250, 1:2,500, 1:12,500, and 1:50,000 scales)

Table 2. (Continued)

Physcial characteristics	Column abbreviations	Type of data	Notes
Physical disturbance score	Phy-dist	categorical	minimum score (2) indicated low disturbance and maximum score (11) indicated high disturbance; scores are as follows:

Vicinity of roadway:

very far	1
intermediate	2
very close	3

Vicinity of houses/buildings:

very far	1
intermediate	2
very close	3

Railway in the area:

absent	0
present	1

Beaver and beaver dam:

absent	0
present	1

Logging in the immediate area:

absent	0
present	1

Borrow pit:

absent	0
present	1

Land-use (e.g., dairy farm, oil refinery):

absent	0
present	1

In-situ stream concentrations of total organic solids (TOS) and total inorganic solids (TIS) were quantified within 1 m of the artificial substrate samplers following the US Environmental Protection Agency's procedures and guidelines (*cited in* McCreadie 1991, Onwubuke 1996). The ratio of TOS:TIS is important because the inorganic fractions dilute the organic fractions or seston that filter-feeding organisms rely on for food (Richardson and Mackay 1991). TOS:TIS estimates were determined from replicate opaque narrow-mouthed bottles (2.0-cm inner mouth-opening diameter, 19.7-cm bottle length) that were left in the streams for one month, during the 1996 sampling period, in order to trap suspended matter in the water column. The bottles were returned to the laboratory and their contents were filtered at 12 mm Hg through pre-ashed (450°C, 1.5 h), pre-weighed Whatman™ GF/C (47-mm diameter) glassfibre filters, dried (60°C, 24 h), cooled (12 h), and re-weighed to estimate the TOS fraction; and then re-ashed, cooled, and re-weighed to estimate the TIS fraction.

Nine physical stream characteristics were measured based on their importance as identified in the literature (Hall *et al.* 1980, Corkum and Currie 1987, Ciborowski and Adler 1990, Hall 1994). These included: average stream current velocity (Avvel), immediate cover (Immcov), proximate cover (Procov), aquatic vegetation (Aqveg), substrate type (Subst), stream order (Order), stream width (Width), upstream pond area (Pond area), and levels of physical disturbance

(Phy-dist) (Table 2).

The average stream current velocity for the two-year period was determined using an A. Ott Kempten current meter held 2.5 cm above the substrate. Immediate cover, proximate cover, and aquatic vegetation were scored on a scale of 1–3 (Table 2). A score of 1 corresponded to an open stream (immediate cover) with no adjacent forest (proximate cover), and no vascular aquatic vegetation in the stream. A score of 3 corresponded to a covered stream with an adjacent forest (proximate cover), and dense vascular aquatic vegetation in the stream. Dense growths of non-vascular filamentous algal were noted when present. Substrate type was based on the dominant visible substrate in three 1-m transects (or stream-width transects if the stream was less than 1 m wide) and scored on a scale of 1–5; adapted from McCreadie (1991) by including a category for wood (Table 2). The five categories of substrate were mud (1), small gravel (2), wood (3), cobble (4), and boulder (5). Stream order and upstream pond area were determined using topographic (1:50,000) and blue-line survey (1:1,250, 1:2,500, 1:12,500, and 1:50,000) maps housed in the map library of the Queen Elizabeth II Library, Memorial University. Pond area was calculated using a Keuffel and Esser compensating polar planimeter and recorded to 0.001 km^2 (courtesy of G. McManus, Cartography Laboratory, Memorial University).

Finally, seven easily observed physical site characteristics were used to reduce the subjectivity in assigning physical disturbance scores at each site (Table 2). This is a modification of the system used in Lomond (1997). The vicinity of roadways and houses/buildings is based on distance measurements from topographic maps (1:50,000) and scored as very far (1), intermediate distance (2), or very close (3) to the outlet site. The presence of a railway, beavers and beaver dams, logging in the immediate area of the stream, a borrow pit, and evidence of land-use such as a dairy farm and an oil refinery is scored as absent (0) or present (1). Therefore, the minimum physical site disturbance score is 2 indicating low physical disturbance and a maximum of 11 indicating high physical disturbance when the scores for the 7 physical characteristics are summed together per each site.

2.2. Biological Variables

2.2.1. *Sampling protocol*

Two standard benthic macroinvertebrate sampling procedures were used to collect simuliid larvae. The qualitative method involved sweeps of lotic and lentic sections of the sites and were examined for taxa missed by the quantitative method. The sweeps were taken with a dip-net (0.1-cm mesh size) no more than 5 m downstream of the outlet and preserved (95% ethanol) for transport back to the laboratory.

The second method involved quantitative samples using three artificial substrates that were placed at each site for colonisation by immature simuliids. The artificial substrates were made from 30-cm plastic mesh bags (2-cm x 1-cm mesh opening) filled with natural gravel (1,000 cm^3, 2.5-cm minimum gravel length). They were placed at each site in May 1995 in locations of maximum current velocities identified with a current meter. The artificial substrates were first retrieved in July 1995, retrieved again in May and July 1996, and finally in May 1997. Each artificial substrate was washed vigorously (3-min) in a bucket, and the contents then sieved (250-µm mesh opening) and preserved (95% ethanol) for transport back to the laboratory where the samples were processed.

2.2.2. *Sorting and identification protocol*

Processing and identification of the qualitative and quantitative samples involved sorting, sub-sampling the sorted samples, and then microscopic identification of the simuliids to determine taxa richness and taxa abundance. The samples were first washed through a sieve series (4.00-mm, 1.19-mm, and 250-µm) to separate the immature simuliids from coarse organic material. Any simuliids trapped by the coarser sieves were added to the contents of the finer sieve and then sub-sampled.

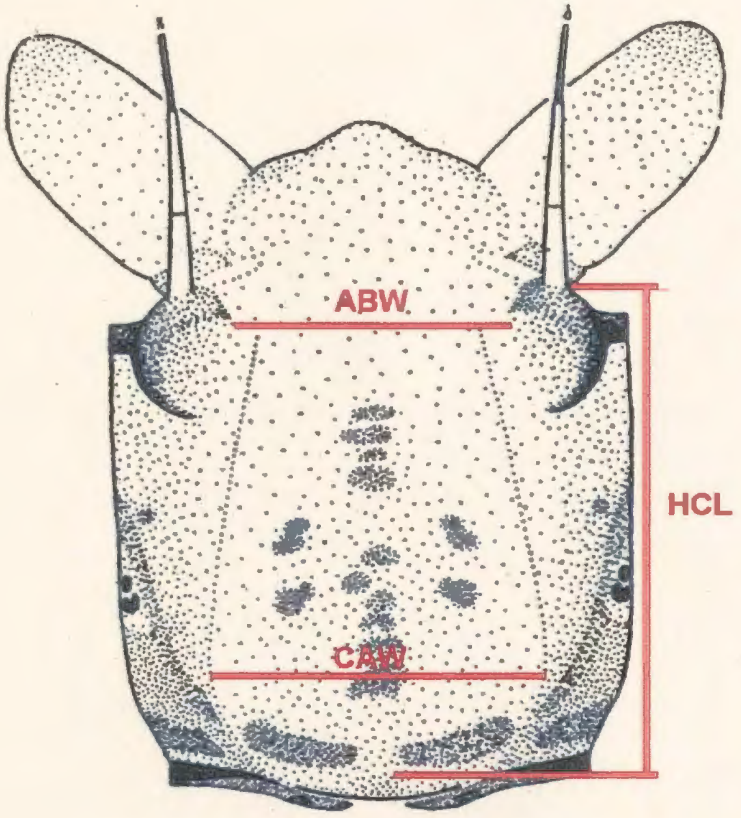
Sub-sampling involved counting the contents of a minimum of five grids on a partitioned petri dish; additional grids were examined if there were fewer than 100 simuliids in the first five grids (Elliot 1977; M. H. Colbo, *personal communication*). The five sub-samples represented 12% (1.4-cm x 1.4-cm grids, square dish) and 13% (2.0-cm x 2.0-cm grids, circular dish) of the entire sample. Simuliids in the sub-samples were identified using a dissecting microscope (60 to 100X magnification); the keys of Wood *et al.* (1963), Stone (1964), Adler and Currie (1986), Currie (1986), Peckarsky *et al.* (1990); reference collections housed in the Biology Department of Memorial University of Newfoundland; and the expertise of Drs. M. H. Colbo and P. H. Adler.

The species complex was the lowest taxonomic unit as no cytological analysis was carried out due to time constraints. The advantage of morphotaxonomic identifications over cytological identifications is the relatively rapid assessment of taxa richness and taxa abundance especially if one is dealing with several hundred samples from several regions and sites. It is acknowledged that information is lost and contradictory results could be obtained when taxa are identified only at the complex level. However, this information loss must be balanced with time constraints in processing samples and the nature of the questions being asked.

2.2.3. *Head capsule measurement protocol*

Ten final-larval instars with black histoblasts of *P. mixtum/fuscum* complex, *S. vittatum*, and *St. mutata* were randomly selected from the May 1997 qualitative and quantitative samples to test for correlations among several environmental variables and sclerite size. These three taxa were selected because they develop over the winter as larvae, and therefore were not affected by fluctuating water temperatures, which has been shown to negatively affect adult size and fecundity under constant food supplies (Colbo and Porter 1979,1981, Colbo 1982, Ross and Merritt 1987).

Three standard linear head capsule measurements were taken from the above taxa using an eyepiece micrometer (300X). The three measurements were head capsule length from the base of the lateral aspect of the head fan stalk to the base of the cephalic cleavage line (HCL), cephalic apotome width at the widest point (CAW), and antennal buttress width between the inner aspects of the buttresses (ABW) (Figure 6; McCreadie and Colbo 1990). These measurements were first compared to confirm size differences associated with the three different taxa. They were then used to determine regional differences that were tested for correlations with selected environmental variables. The head capsule measurements were also used to determine size differences associated with increasing stream size within a watershed in a region.



P. mixtum

Figure 6. Location of the three head capsule measurements taken from final-larval instars. HCL is the head capsule length from the base of the lateral aspect of the head fan stalk to the base of the cephalic cleavage line. CAW is the cephalic apotome width at the widest point. ABW is the antennal buttress width between the inner aspects of the buttresses.

2.3. Data and Statistical Analyses

A graphical and two statistical packages were used to analyse for significant regional and site differences, and significant correlations among the environmental and biological data. SigmaPlot (Release 4.0) was used to create box and scatter plots for preliminary analyses of the data. Minitab (Release 11.12) was used to perform parametric and non-parametric univariate statistical comparisons among the environmental and biological data. Multivariate data analyses were also performed using Minitab, while SAS (Release 6.12) was used to perform parametric and non-parametric correlation analyses among the environmental and biological data. Significance was reported at $\alpha = 0.05$ and $\alpha = 0.01$. SAS was used for correlation analyses because it produced *p*-values that were missing in the Minitab outputs. Nevertheless, the correlation coefficients were the same in both programmes.

Prior to the univariate statistical analyses, the raw data for the entire study period were transformed to normalise their distribution, except as indicated. The chemical data after converting all ion concentrations to mg/mL were Ln(x+1)-transformed, except for pH which was already on a log scale. The physical data were not transformed. Taxa richness and taxa abundance were first pooled to obtain a representative value for the entire study period. Pooling the biological data involved the summation of the estimated numbers of individuals (abundance) per site across the four sampling dates, and the summation of the number of taxa (richness) per site

across the four sampling dates respectively. The pooled taxa abundance data was Ln(x+1)-transformed. The pooled taxa richness was not transformed. Final-larval instar head capsules measurements were not transformed for the univariate analyses as their distributions were already normal.

Prior to the multivariate analyses, the raw data were reduced except as indicated to obtain a representative value for the entire study period as multivariate tests emphasise relative rather than absolute differences in site-specific characteristics when relating environmental and biological data (Ciborowski and Adler 1990). As with the univariate analyses, the chemical data were Ln(x+1)-transformed and averaged over the study period. The physical data were not transformed. TOS and TIS were excluded from the multivariate analyses because of missing values. Taxa richness and abundance were pooled over the study period. The pooled taxa richness data were not transformed, but the pooled taxa abundance data were coded after being transformed into octaves following the method outlined in Ciborowski and Adler (1990). More specific details about each statistical procedures used are included in the results.

3.0. RESULTS

Univariate and multivariate statistics were used to determine significant regional and site differences in the environmental and biological data to address the objectives of this study. These statistics highlight the complex nature of the data as it is often the relative rather than the absolute differences in the variables being examined that explain observed patterns in the data (Ciborowski and Adler 1990, Fore *et al.* 1996). The univariate results of the regional analyses are reported first, followed by the results of the site analyses and the correlation analyses for significant associations among the environmental and biological data. The multivariate results and correlations are reported last.

3.1. Regional Results of the Environmental and Biological Data Using Univariate Statistics

Regional differences in the environmental and biological data were expected. One-way ANOVAs were first performed on the environmental and pooled taxa richness and pooled taxa abundance data; the residuals however were not normal even after the Ln(x+1)-transformation of the chemical and physical environmental and pooled taxa abundance data. Therefore, non-parametric Kruskal-Wallis tests were used to determine regional differences in the data. A Bonferroni correction was applied to the standard *p*-value to reduce the probability of making a Type I Error

associated with numerous comparisons (Sokal and Rohlf 1995; M. H. Colbo, J. W. McCreadie, and D. C. Schneider, *personal communication*). However, the chemical, physical, and biological results were reported only as significant at $\alpha < 0.05$ and $\alpha < 0.01$ to reduce the probability of making a Type II Error which is associated with a Bonferroni correction after the *p*-values were adjusted for ties in the ranking procedure. An one-way ANOVA and a Tukey's pairwise comparison was used to determine significant head capsule size differences in three taxa, four regions, and several sites.

3.1.1. *Regional chemical data*

The mean and range of values for the 12 chemical variables are reported in Table 3. The mean values were representative of the data collected over the study period since their means were equal to their median values, except for SO_4^{2-} concentration whose May 1995 values were two orders of magnitude higher than the remaining SO_4^{2-} values. However, for purposes of this study, the mean SO_4^{2-} concentration was used.

The Kruskal-Wallis test showed significant regional mean-ranked differences in conductivity, pH, and all the ions except for Cu^{2+} (Table 4). For conductivity ($p = 0.000$, df = 3), St. John's had the highest mean-ranked value followed by Random Island, Bonavista, and Come-by-Chance.

Table 3. Mean and range of 12 chemical environmental variables from 23 sites. The range are in brackets. Total inorganic (TIS) and total organic (TOS) solids were collected only in July 1996. Missing values (-) represented undetectable concentrations of Al^{3+} and no samples of TIS and TOS due to the samplers being washed away from where they were anchored in the stream.

Site designation (local name)	pH	Conductivity (µS/cm)	SO_4^{2-} (mg/L)
Bonavista			
B1 (Beaver/Hospital Pond)	6.5 (6.1 - 6.9)	96.5 (68.5 - 150.0)	23.6 (2.5 - 144.4)
B2 (Long Pond)	5.9 (5.2 - 6.6)	60.1 (52.2 - 67.7)	14.5 (2.3 - 86.3)
B3	5.6 (4.7 - 6.4)	52.4 (44.2 - 67.0)	32.1 (1.5 - 214.4)
B6	6.2 (5.9 - 6.7)	68.6 (49.7 - 80.0)	21.0 (1.5 - 115.5)
B7	5.9 (5.3 - 6.5)	54.0 (46.2 - 67.0)	32.7 (1.9 - 185.8)
B8 (Beaver Pond)	5.8 (5.3 - 6.5)	47.2 (36.5 - 61.0)	42.1 (1.5 - 242.7)
B18	6.7 (6.4 - 6.9)	98.1 (95.8 - 100.0)	3.7 (3.4 - 3.9)
Random Island			
R9 (Long Pond)	7.2 (6.6 - 7.5)	94.3 (86.0 - 114.9)	11.7 (3.6 - 51.7)
R10 (Birchy Pond)	6.8 (6.3 - 7.2)	91.2 (81.0 - 106.0)	7.3 (2.3 - 36.0)
R11 (Beaver Pond)	7.2 (6.8 - 7.5)	86.7 (80.5 - 92.8)	9.0 (2.2 - 41.7)
R13 (Tween Bridge Pond)	6.9 (6.6 - 7.1)	41.1 (34.2 - 46.7)	10.2 (2.1 - 49.2)
R19 (Little Deans Cove Pond)	6.8 (6.3 - 7.2)	44.8 (43.9 - 46.0)	3.1 (3.0 - 3.0)
Come-by-Chance			
C14	5.9 (4.3 - 6.9)	31.7 (23.1 - 38.0)	40.4 (3.3 - 222.0)
C15 (Middle Pond)	6.5 (6.1 - 6.8)	45.6 (42.6 - 49.1)	23.1 (3.5 - 119.7)
C16 (Lower Pond)	6.5 (6.0 - 7.1)	36.1 (30.8 - 39.8)	20.1 (3.3 - 102.4)
C17 (Upper Pond)	6.3 (5.6 - 6.8)	45.8 (39.4 - 54.0)	15.6 (3.5 - 86.0)

Table 3. (Continued)

Site designation (local name)	pH	Conductivity (µS/cm)	SO_4^{2-} (mg/L)
Mt. Pearl, St. John's, Paradise			
S20 (Brazil Pond)	6.6 (6.5 - 6.8)	311.3 (205.0 - 511.0)	7.1 (6.2 - 8.1)
S21 (Power Pond)	6.7 (6.5 - 7.0)	495.7 (400.0 - 672.0)	12.1 (9.7 - 14.6)
S22 (Branscombes Pond)	6.4 (6.2 - 6.8)	186.3 (140.0 - 216.0)	4.3 (3.0 - 5.5)
S23 (Long Pond)	6.6 (6.2 - 7.0)	259.0 (215.0 - 301.0)	7.1 (6.0 - 8.2)
S24 (Kents Pond)	7.1 (6.7 - 7.3)	1,359.0 (1,050.0 - 1,915.0)	19.9 (16.6 - 22.8)
S25 (Virginia Lake)	7.0 (6.7 - 7.3)	395.0 (280.0 - 610.0)	9.9 (8.7 - 11.2)
S26 (Georges Pond)	6.7 (6.4 - 6.9)	288.3 (240.0 - 318.0)	6.6 (6.5 - 6.7)

Table 3. (Continued)

Site designation (local name)	Mg^{2+} (mg/L)	Zn^{2+} (µg/L)	Al^{3+} (µg/L)
Bonavista			
B1 (Beaver/Hospital Pond)	1.0 (0.74 - 1.23)	5.9 (2.9 - 10.2)	53.1 (22.0 - 73.0)
B2 (Long Pond)	0.8 (0.63 - 0.85)	5.1 (3.3 - 7.4)	54.3 (33.0 - 72.0)
B3	0.8 (0.60 - 1.03)	6.0 (2.9 - 13.9)	115.9 (19.0 - 206.0)
B6	1.0 (0.79 - 1.24)	3.8 (2.1 - 11.5)	93.2 (69.0 - 209.0)
B7	0.8 (0.55 - 0.93)	4.3 (2.6 - 6.6)	119.3 (90.0 - 200.0)
B8 (Beaver Pond)	0.9 (0.69 - 1.07)	3.6 (2.4 - 8.1)	71.8 (46.0 - 97.0)
B18	1.0 (0.95 - 0.98)	2.0 (1.3 - 2.5)	59.2 (19.0 - 154.0)
Random Island			
R9 (Long Pond)	1.0 (0.90 - 1.12)	2.1 (1.0 - 3.0)	26.0 (19.0 - 36.0)
R10 (Birchy Pond)	1.4 (1.30 - 1.58)	2.2 (1.3 - 3.4)	18.0 (10.0 - 32.0)
R11 (Beaver Pond)	1.2 (1.01 - 1.29)	4.0 (1.1 - 16.4)	15.2 (-10.0 - 20.0)
R13 (Tween Bridge Pond)	0.6 (0.49 - 0.69)	1.2 (0.9 - 1.5)	40.8 (23.0 - 71.0)
R19 (Little Deans Cove Pond)	0.8 (0.79 - 0.82)	2.0 (1.0 - 3.7)	15.5 (12.0 - 20.0)
Come-by-Chance			
C14	0.6 (0.41 - 0.71)	1.1 (2.1 - 21.1)	107.4 (63.0 - 173.0)
C15 (Middle Pond)	0.7 (0.52 - 0.73)	3.6 (1.8 - 7.6)	78.8 (45.0 - 113.0)
C16 (Lower Pond)	0.6 (0.47 - 0.71)	3.0 (1.9 - 5.6)	95.8 (46.0 - 147.0)
C17 (Upper Pond)	0.7 (0.46 - 0.72)	3.7 (1.5 - 9.5)	86.4 (42.0 - 127.0)

Table 3. (Continued)

Site designation (local name)	Mg^{2+} (mg/L)	Zn^{2+} (µg/L)	Al^{3+} (µg/L)
Mt. Pearl, St. John's, Paradise			
S20 (Brazil Pond)	1.2 (1.18 - 1.20)	4.2 (2.8 - 5.2)	39.5 (16.0 - 58.0)
S21 (Power Pond)	1.3 (1.09 - 1.47)	22.2 (18.8 - 27.7)	38.0 (26.0 - 52.0)
S22 (Branscombes Pond)	1.2 (1.07 - 1.40)	4.5 (3.4 - 5.1)	32.5 (31.0 - 41.0)
S23 (Long Pond)	1.0 (0.97 - 1.08)	17.8 (16.6 - 18.7)	72.8 (35.0 - 116.0)
S24 (Kents Pond)	2.8 (2.77 - 2.90)	5.2 (3.7 - 6.8)	-
S25 (Virginia Lake)	1.7 (1.70 - 1.78)	9.6 (6.0 - 11.4)	26.0 (20.0 - 34.0)
S26 (Georges Pond)	1.1 (1.09 - 1.16)	4.2 (3.3 - 5.8)	14.0 (-10.0 - 28.0)

Table 3. (Continued)

Site designation (local name)	Ca^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)
Bonavista			
B1 (Beaver/Hospital Pond)	2.0 (1.14 - 2.75)	0.3 (-0.1 - 0.4)	12.9 (8.47 - 17.99)
B2 (Long Pond)	1.0 (0.85 - 1.11)	0.3 (0.2 - 0.5)	8.2 (6.69 - 9.19)
B3	1.1 (0.74 - 1.52)	0.2 (0.4 - 0.4)	7.2 (5.58 - 9.18)
B6	1.4 (1.15 - 1.82)	0.3 (0.1 - 0.4)	9.1 (6.51 - 10.36)
B7	1.1 (0.74 - 1.31)	0.3 (0.2 - 0.3)	8.1 (6.03 - 9.24)
B8 (Beaver Pond)	1.0 (0.77 - 1.31)	0.3 (0.1 - 0.4)	6.6 (5.72 - 7.43)
B18	2.0 (1.95 - 1.99)	0.4 (0.3 - 0.5)	13.6 (13.46 - 13.78)
Random Island			
R9 (Long Pond)	4.9 (4.62 - 5.08)	0.5 (0.3 - 0.9)	9.7 (8.98 - 10.59)
R10 (Birchy Pond)	3.2 (2.90 - 3.66)	0.7 (0.5 - 0.9)	9.5 (8.77 - 11.47)
R11 (Beaver Pond)	7.8 (6.79 - 8.23)	0.4 (0.3 - 0.5)	6.6 (5.72 - 7.19)
R13 (Tween Bridge Pond)	3.0 (2.20 - 3.33)	0.3 (0.1 - 0.5)	3.6 (3.00 - 4.03)
R19 (Little Deans Cove Pond)	3.6 (3.61 - 3.65)	0.3 (0.1 - 0.4)	3.2 (3.18 - 3.23)
Come-by-Chance			
C14	2.1 (1.63 - 2.33)	0.2 (0.1 - 0.3)	3.4 (3.18 - 3.62)
C15 (Middle Pond)	2.9 (2.43 - 3.04)	0.3 (0.2 - 0.4)	5.0 (4.23 - 6.32)
C16 (Lower Pond)	2.6 (1.85 - 2.87)	0.3 (0.2 - 0.3)	3.4 (3.07 - 3.70)
C17 (Upper Pond)	2.6 (1.79 - 2.90)	0.3 (0.2 - 0.4)	4.9 (4.15 - 6.15)

Table 3. (Continued)

Site designation (local name)	Ca^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)
Mt. Pearl, St. John's, Paradise			
S20 (Brazil Pond)	4.6 (4.39 - 4.83)	0.8 (0.6 - 0.9)	38.5 (31.28 - 45.89)
S21 (Power Pond)	7.7 (6.04 - 9.23)	1.0 (0.8 - 1.1)	87.0 (64.56 - 109.26)
S22 (Branscombes Pond)	4.4 (3.45 - 5.34)	0.5 (0.3 - 0.6)	29.3 (27.35 - 31.20)
S23 (Long Pond)	5.2 (4.85 - 5.48)	0.9 (0.9 - 1.0)	43.8 (39.57 - 47.88)
S24 (Kents Pond)	16.8 (15.52 - 18.09)	2.1 (1.8 - 2.3)	109.7 (-0.01 - 221.84)
S25 (Virginia Lake)	7.3 (6.75 - 7.80)	1.1 (1.0 - 1.1)	53.2 (42.35 - 64.04)
S26 (Georges Pond)	3.4 (3.39 - 3.49)	0.8 (0.7 - 1.0)	50.1 (48.86 - 50.91)

Table 3. (Continued)

Site designation (local name)	Cu^{2+} (µg/L)	TIS (µg/mL)	TOS (µg/mL)
Bonavista			
B1 (Beaver/Hospital Pond)	3.7 (1.0 - 12.0)	0.2912	0.1420
B2 (Long Pond)	4.0 (2.0 - 11.0)	0.1303	0.0709
B3	8.1 (2.0 - 27.0)	-	-
B6	5.8 (2.0 - 23.0)	0.1881	0.0984
B7	5.2 (2.0 - 14.0)	0.0397	0.0417
B8 (Beaver Pond)	4.2 (1.0 - 11.0)	-	-
B18	1.8 (1.0 - 3.0)	0.1068	0.1206
Random Island			
R9 (Long Pond)	3.8 (2.0 - 7.0)	0.2462	0.1093
R10 (Birchy Pond)	4.9 (2.0 - 11.0)	1.1701	0.5792
R11 (Beaver Pond)	2.3 (1.0 - 5.0)	-	-
R13 (Tween Bridge Pond)	2.0 (1.0 - 5.0)	0.6760	0.2222
R19 (Little Deans Cove Pond)	1.5 (1.0 - 2.0)	-	-
Come-by-Chance			
C14	6.6 (1.0 - 22.0)	-	-
C15 (Middle Pond)	2.8 (1.0 - 7.0)	0.1009	0.0782
C16 (Lower Pond)	3.5 (2.0 - 6.0)	-	-
C17 (Upper Pond)	3.7 (1.0 - 9.0)	0.3176	0.1464

Table 3. (Continued)

Site designation (local name)	Cu^{2+} (µg/L)	TIS (µg/mL)	TOS (µg/mL)
Mt. Pearl, St. John's, Paradise			
S20 (Brazil Pond)	2.2 (1.0 - 3.0)	0.0280	0.0540
S21 (Power Pond)	3.8 (3.0 - 4.0)	-	-
S22 (Branscombes Pond)	2.0	0.1940	0.0810
S23 (Long Pond)	4.0	0.1690	0.0450
S24 (Kents Pond)	3.0	-	-
S25 (Virginia Lake)	3.0	0.4080	0.1320
S26 (Georges Pond)	3.0 (2.0 - 4.0)	0.0600	0.0280

Table 4. Kruskal-Wallis results testing for significant regional differences in 21 environmental variables, pooled taxa richness, and pooled taxa abundance of simuliids. The Kruskal-Wallis results are adjusted for tied ranks.

	Adjusted Kruskal-Wallis	df	Adjusted *p*-value	
Conductivity	66.56	3	0.000	**
pH	41.96	3	0.000	**
SO_4^{2-}	13.51	3	0.004	**
Mg^{2+}	30.51	3	0.000	**
Zn^{2+}	19.16	3	0.000	**
Al^{3+}	19.02	3	0.000	**
Ca^{2+}	49.03	3	0.000	**
K^{+}	37.00	3	0.000	**
Na^{+}	35.32	3	0.000	**
Cu^{2+}	2.00	3	ns	
TOS	5.54	3	ns	
TIS	4.88	3	ns	
Immediate cover score	4.26	3	ns	
Proximate cover score	8.95	3	0.030	*
Aquatic vegetation score	1.41	3	ns	
Substrate score	1.74	3	ns	
Stream order	1.01	3	ns	
Stream width	2.95	3	ns	
Physical disturbance score	8.38	3	0.039	*
Taxa richness	6.86	3	ns	
Taxa abundance	3.44	3	ns	

* $\alpha < 0.05$, ** $\alpha < 0.01$, and ns not significant

For pH (p = 0.000, df = 3), Random Island had the highest mean-ranked value followed by St. John's, Come-by-Chance, and Bonavista. St. John's had the highest mean-ranked concentrations of Ca^{2+} (p = 0.000, df = 3), K^{+} (p = 0.000, df = 3), and Na^{+} (p = 0.000; df = 3), but Bonavista had the lowest mean-ranked Ca^{2+} (p = 0.000, df = 3) and K^{+} (p = 0.000, df = 3) values, and Come-by-Chance had the lowest mean-ranked Na^{+} (p = 0.000, df = 3) value. For concentration of Mg^{2+} (p = 0.000, df = 3), St. John's had the highest mean-ranked value followed by Random Island, Bonavista, and Come-by-Chance. For concentration of Zn^{2+} (p = 0.000, df = 3), St. John's had the highest mean-ranked value followed by Bonavista, Come-by-Chance, and Random Island. For concentration of SO_4^{2-} (p = 0.004, df =3), Bonavista had the highest mean-ranked value followed by Random Island, Come-by-Chance, and St. John's. For concentration of Al^{3+} (p = 0.000, df = 3), Bonavista had the highest mean-ranked value followed by Come-by-Chance, St. John's, and Random Island.

The Kruskal-Wallis test showed no significant regional differences in mean-ranked concentrations of Cu^{2+}, TOS, and TIS (Table 4). However, there were marginal differences in the above chemical variables worth mentioning. Bonavista had slightly higher mean concentration of Cu^{2+} than Random Island, Come-by-Chance, and St. John's which had similar values. Random Island had slightly higher mean TOS and TIS concentrations followed by Come-by-Chance, Bonavista, and St. John's which had similar values.

3.1.2. *Regional physical data*

The values for the seven physical variables are reported in Table 5. Unlike the chemical data, the physical data were measured only once. The Kruskal-Wallis test showed no significant regional mean-ranked differences in the scores for immediate cover, aquatic vegetation, substrate, stream order, and measurement of stream width, but significant regional mean-ranked differences in the scores for proximate cover (p = 0.030, df = 3) and physical disturbance (p = 0.039, df = 3) (Table 4). Random Island was forested compared to Bonavista and St. John's which had scrub-forests, and Come-by-Chance which was open in terms of its mean proximate cover. Random Island had a higher mean physical disturbance score than St. John's followed by Bonavista and Come-by-Chance.

3.1.3. *Regional taxa richness and taxa abundance*

Taxa richness and taxa abundance were examined for regional differences. The Kruskal-Wallis test showed no significant regional differences in the pooled taxa richness (Table 4), even though St. John's had more taxa than Random Island, Bonavista, and Come-by-Chance; Come-by-Chance had the fewest taxa (Table 6). Taxa richness (numbers of simuliid taxa) was pooled because the mean values were not true representatives of the two-year data as the means were not equal to the medians (Figure 7).

Table 5. Nine physical environmental variables from 23 sites. Average current velocity is the mean across the sampling periods and stream width is the mean of three readings per site. Refer to Table 2 on how the categorial variables were scored.

Site designation (local names)	Average velocity (Avvel) (m/s)	Immediate cover (Immcov)	Proximate cover (Procov)	Aquatic vegetation (Aqveg)	Substrate (Subst)
Bonavista					
B1 (Beaver/Hospital Pond)	0.57	1	1	3	4
B2 (Long Pond)	0.47	1	3	1	5
B3	0.52	2	2	3	5
B6	0.41	1	2	2	2
B7	0.51	1	2	1	5
B8 (Beaver Pond)	0.46	2	3	1	4
B18	0.50	1	3	1	4
Random Island					
R9 (Long Pond)	0.64	1	3	2	4
R10 (Birchy Pond)	0.41	3	3	1	1
R11 (Beaver Pond)	0.44	3	3	1	4
R13 (Tween Bridge Pond)	0.81	1	3	1	5
R19 (Little Deans Cove Pond)	0.50	3	3	2	2
Come-by-Chance					
C14	0.18	1	1	2	3
C15 (Middle Pond)	0.41	2	1	1	5
C16 (Lower Pond)	0.54	2	2	2	4
C17 (Upper Pond)	0.55	2	2	1	4

Table 5. (Continued)

Site designation (local names)	Average velocity (Avvel) (m/s)	Immediate cover (Immcov)	Proximate cover (Procov)	Aquatic vegetation (Aqveg)	Substrate (Subst)
Mt. Pearl, St. John's, Paradise					
S20 (Brazil Pond)	0.37	2	3	1	2
S21 (Power Pond)	0.57	1	2	1	4
S22 (Branscombes Pond)	0.32	3	3	1	2
S23 (Long Pond)	0.82	1	3	1	5
S24 (Kents Pond)	0.16	2	2	1	4
S25 (Virginia Lake)	0.83	2	3	3	5
S26 (Georges Pond)	0.40	3	1	1	2

Table 5. (Continued)

Site designation (local names)	Physical disturbance (Phy-dist)	Stream order (Order)	Stream width (Width) (m)	Pond area (km^2)
Bonavista				
B1 (Beaver/Hospital Pond)	9	3	11.2	0.226
B2 (Long Pond)	4	3	7.5	0.597
B3	7	2	2.5	0.013
B6	5	1	3.3	0.017
B7	4	3	6.8	0.076
B8 (Beaver Pond)	7	1	1.9	0.030
B18	6	1	0.7	0.141
Random Island				
R9 (Long Pond)	8	1	1.4	0.085
R10 (Birchy Pond)	8	1	2.0	0.041
R11 (Beaver Pond)	9	2	2.1	0.017
R13 (Tween Bridge Pond)	8	4	8.5	0.002
R19 (Little Deans Cove Pond)	4	1	1.0	0.039
Come-by-Chance				
C14	6	1	1.6	0.043
C15 (Middle Pond)	3	2	1.7	0.032
C16 (Lower Pond)	4	2	2.4	0.049
C17 (Upper Pond)	3	2	2.3	0.052

Table 5. (Continued)

Site designation (local names)	Physical disturbance (Phy-dist)	Stream order (Order)	Stream width (Width) (m)	Pond area (km^2)
Mt. Pearl, St. John's, Paradise				
S20 (Brazil Pond)	8	1	1.0	0.044
S21 (Power Pond)	9	1	1.0	0.017
S22 (Branscombes Pond)	8	1	0.7	0.022
S23 (Long Pond)	7	3	6.5	0.137
S24 (Kents Pond)	7	1	2.7	0.090
S25 (Virginia Lake)	6	3	2.7	0.216
S26 (Georges Pond)	5	1	0.8	0.052

Table 6. Pooled taxa richness of 16 simuliid taxa collected from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during July 1995, May and July 1996, and May 1997. The simuliid taxa are listed in decreasing order of presence (+), and the four regions and sites within regions are arranged in decreasing order of taxa richness. The adjusted taxa richness which excluded prevalent* (i. e., taxa collected from all sites) and rare** (i. e., taxa collected from ≤ 2 sites) pooled taxa was used only for the multivariate analysis. Values in ( ) are corrected for mis-identified taxon.

Taxa	S22	S26	S20	S25	S21	S23	S24	R11	R19	R13	R10	R9
S. venustum/verecundum complex*	+	+	+	+	+	+	+	+	+	+	+	+
S. vittatum	+	+	+	+	+	+		+			+	+
St. mutata	+	+	+					+	+	+	+	+
E. craigi/caledonense complex°	+	+	+	+			+	+	+	+		
P. mixtum/fuscum complex°°	+		+					+	+	+	+	+
S. decorum	+	+	+	+					+		+	
S. tuberosum			+					+	+	+		
E. aureum	+	+						+	+	+	+	
C. ornithophilia	+								+			
E. canonicolum †	+ ( )	+ ( )						+ ( )	+ ( )			
E. furculatum	+	+										
S. corbis				+						+		+
*E. aestivum*** ††	+ ( )							+ ( )				
*E. euryadminiculum***	+	+										
*E. excisum*** †††	+ ( )							+ ( )				
*E. croxtoni***	+											
Pooled taxa richness per site	14 (11)	9 (8)	7	5	2	2	2	10 (7)	9 (8)	7	6	5
Pooled taxa richness per region				16						13		
Adjusted pooled taxa richness per site	9 (8)	7	6	4	1	1	1	7 (6)	8 (7)	6	5	4
Adjusted pooled taxa richness per region				11						10		

Notes:
° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
°° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
††† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Table 6. (Continued)

Taxa	B7	B18	B6	B1	B3	B2	B8	C16	C17	C15	C14
S. venustum/verecundum complex*	+	+	+	+	+	+	+	+	+	+	+
S. vittatum	+	+	+	+	+	+	+	+	+	+	+
St. mutata	+	+	+	+	+	+	+	+	+	+	+
E. craigi/caledonense complex°	+	+	+		+			+	+	+	+
P. mixtum/fuscum complex°°	+	+	+	+	+	+		+	+	+	
S. decorum	+	+	+	+				+	+		
S. tuberosum	+	+	+	+				+	+		
E. aureum						+					
C. ornithophilia	+	+		+	+	+					
E. canonicolum †	+ ( )	+ ( )									
E. furculatum											+
S. corbis											
*E. aestivum*** ††											
*E. euryadminiculum***											
*E. excisum*** †††											
*E. croxtoni***											
Pooled taxa richness per site	9 (8)	9 (8)	7	7	6	6	3	7	7	5	5
Pooled taxa richness per region				12						8	
Adjusted pooled taxa richness per site	8 (7)	8 (7)	6	6	5	5	2	6	6	4	4
Adjusted pooled taxa richness per region				9						7	

Notes:
° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
°° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
††† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

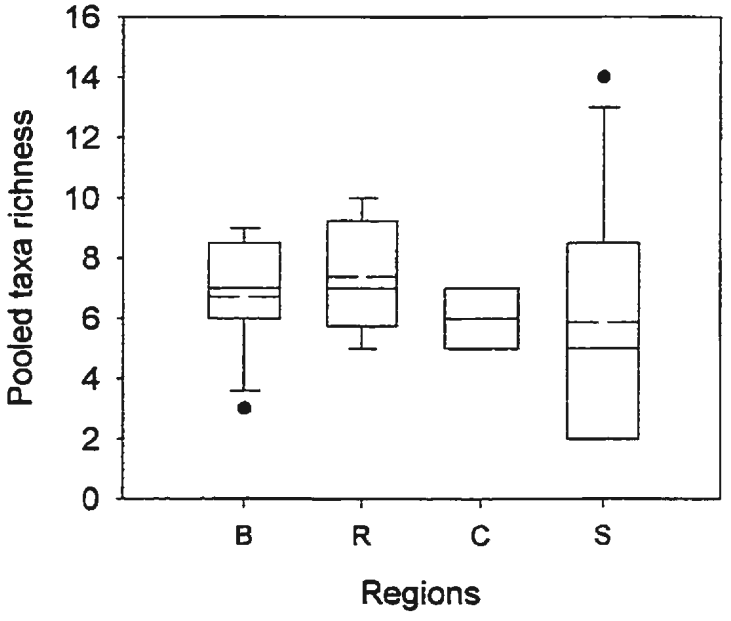


Figure 7. Boxplots of the two-year pooled simuliid taxa richness data from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S). The mean values per region (--) are not equal to the median values per region (-). Figure 7 uses the pooled taxa richness per site data, not adjusted for the mis-identified taxa, from Table 6.

The Kruskal-Wallis test also showed no significant regional differences in the pooled taxa abundance (Table 4), even though Random Island had more simuliids than the other sites; Come-by-Chance had the fewest number of simuliids (Table 7). Taxa abundance (numbers of simuliid individuals) were first pooled and then Ln(x+1)-transformed to normalise its distribution. Taxa abundance was pooled because the mean regional values were not equal to the median regional values (Figure 8). Regardless of the lack of significant regional differences in pooled taxa richness and pooled taxa abundance, there were site differences that were examined starting in a Section 3.2.

3.1.4. *Regional head capsule sizes of three simuliid taxa*

Besides regional taxa richness and taxa abundance, final-larval instar head capsule sizes were examined for taxa and regional differences. An one-way ANOVA and Tukey's pairwise comparison showed significant differences in mean head capsule sizes of *P. mixtum/fuscum*, *S. vittatum*, and *St. mutata* (Table 8). A parametric test was used because the mean and median values were equal indicating that the data were normally distributed. *Simulium vittatum* final-larval instars had the longest and widest mean head capsule. *Stegopterna mutata* final-larval instars had the shortest mean head capsule, but *P. mixtum/fuscum* had the narrowest mean head capsule.

Table 7. Pooled abundance of 16 simuliid taxa collected from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during July 1995, May and July 1996, and May 1997. Percentages are in brackets and the simuliid taxa are listed in decreasing order of abundance for the four regions and sites within regions. Prevalent taxon is indicated by * and rare taxa are indicated by **. The adjusted pooled taxa abundance which excluded rare taxa (i.e., taxa collected from ≤ 2 sites) was used only for the multivariate analysis. Values in [ ] are corrected for mis-identified taxon.

Taxa	R19		R9		R11		R13		R10	
S. venustum/verecundum complex*	58983	(73.5)	17525	(98.0)	8539	(72.1)	1259	(40.4)	2078	(90.5)
St. mutata	17588	(21.9)	198	(1.1)	197	(1.7)	5	(0.2)	138	(6.0)
S. vittatum	0	(0.0)	157	(0.9)	2941	(24.8)	0	(0.0)	41	(1.8)
C. ornithophilia	63	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
P. mixtum/fuscum complex°	1236	(1.5)	7	(0.0)	24	(0.2)	66	(2.1)	2	(0.1)
E. craigi/caledonense complex°°	65 [73]	(0.1)	0	(0.0)	19 [20]	(0.2)	1	(0.0)	0	(0.0)
S. tuberosum	2091	(2.6)	0	(0.0)	6	(0.1)	341	(10.9)	0	(0.0)
S. corbis	0	(0.0)	1	(0.0)	0	(0.0)	1442	(46.3)	0	(0.0)
S. decorum	58	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)	10	(0.4)
E. aureum	121	(0.2)	0	(0.0)	106 [117]	(0.9) [1.0]	2	(0.1)	28	(1.2)
E. canonicolum †	8 [0]	(0.0)	0	(0.0)	1 [0]	(0.0)	0	(0.0)	0	(0.0)
*E. croxtoni***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. euryadminiculum***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
E. furculatum	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. excisum*** ††	0	(0.0)	0	(0.0)	1 [0]	(0.0)	0	(0.0)	0	(0.0)
*E. aestivum*** †††	0	(0.0)	0	(0.0)	10 [0]	(0.1)	0	(0.0)	0	(0.0)
Pooled abundance per site	80214		17888		11843		3116		2296	
Pooled abundance per region	115357									
Adjusted pooled abundance per site	80141		17888		11706		3116		2296	
Adjusted pooled abundance per region	115147									

Notes:
° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
°° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
††† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.

Table 7. (Continued)

Taxa	S20	S22	S26	S24	S25	S21	S23
S. venustum/verecundum°	44819 (92.6)	514 (2.7)	38 (2.1)	126 (14.1)	291 (68.6)	22 (71.0)	2 (12.5)
St. mutata	2539 (5.2)	474 (2.5)	5 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
S. vittatum	168 (0.3)	1 (0.0)	3 (0.2)	0 (0.0)	126 (29.7)	9 (29.0)	14 (87.5)
C. ornithophilia	0 (0.0)	13566 (71.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
P. mixtum/fuscum complex°	417 (0.9)	2674 (14.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
E. craigi/caledonense complex°°	468 (1.0)	1455 [1584] (7.6) [8.3]	1695 [1697] (94.6) [94.7]	764 (85.9)	2 (0.5)	0 (0.0)	0 (0.0)
S. tuberosum	7 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
S. corbis	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.7)	0 (0.0)	0 (0.0)
S. decorum	7 (0.0)	7 (0.0)	4 (0.2)	0 (0.0)	2 (0.5)	0 (0.0)	0 (0.0)
E. aureum	0 (0.0)	1 [9] (0.0)	6 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
E. canonicolum †	0 (0.0)	95 [0] (0.5)	2 [0] (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
*E. croxtoni***	0 (0.0)	114 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
*E. euryadminiculum***	0 (0.0)	102 (0.5)	3 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
E. furculatum	0 (0.0)	30 (0.2)	36 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
*E. excisum*** ††	0 (0.0)	34 [0] (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
*E. aestivum*** †††	0 (0.0)	8 [0] (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Pooled abundance per site	48425	19076	1792	890	424	31	16
Pooled abundance per region	70654						
Adjusted pooled abundance per site	48425	17266	92	890	424	31	16
Adjusted pooled abundance per region	67145						

Notes:
° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
°° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
††† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.

Table 7. (Continued)

Taxa	B18		B2		B7		B6		B1		B3		B8	
S. venustum/verecundum complex°	18446	(53.9)	1305	(7.4)	4178	(42.4)	2773	(85.7)	1147	(49.1)	431	(72.7)	113	(57.1)
St. mutata	6258	(18.3)	754	(4.3)	1109	(11.3)	2	(0.1)	14	(0.6)	15	(2.5)	25	(12.6)
S. vittatum	624	(1.8)	15529	(88.2)	4240	(43.1)	450	(13.9)	1129	(48.3)	14	(2.4)	60	(30.3)
C. ornithophilla	5237	(15.3)	7	(0.0)	19	(0.2)	0	(0.0)	17	(0.7)	2	(0.3)	0	(0.0)
P. mixtum/fuscum complex°	3525	(10.3)	7	(0.0)	172	(0.8)	2	(0.1)	22	(0.9)	122	(20.6)	0	(0.0)
E. craigi/caledonense complex°°	94 [101]	(0.3)	0	(0.0)	31 [35]	(0.3)	1	(0.0)	0	(0.0)	9	(1.5)	0	(0.0)
S. tuberosum	34	(0.1)	0	(0.0)	28	(0.3)	1	(0.0)	2	(0.1)	0	(0.0)	0	(0.0)
S. corbis	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
S. decorum	17	(0.1)	0	(0.0)	66	(0.7)	8	(0.2)	6	(0.3)	0	(0.0)	0	(0.0)
E. aureum	0	(0.0)	15	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
E. canonicolum †	7 [0]	(0.0)	0	(0.0)	4 [0]	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. croxtoni***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. euryadminiculum***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
E. furculatum	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. excisum*** ††	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. aestivum*** †††	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Pooled abundance per site	34241		17618		9848		3237		2337		593		198	
Pooled abundance per region	68071													
Adjusted pooled abundance per site	34140		17618		9813		3237		2337		593		198	
Adjusted pooled abundance per region	67936													

Notes:
° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
°° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
††† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.

Table 7. (Continued)

Taxa	C17		C15		C16		C14	
S. venustum/verecundum complex*	30566	(97.7)	15176	(90.4)	11891	(91.7)	27	(39.7)
St. mutata	14	(0.0)	843	(5.0)	117	(0.9)	2	(2.9)
S. vittatum	497	(1.6)	576	(3.4)	672	(5.2)	8	(11.8)
C. ornithophilia	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
P. mixtum/fuscum complex°	1	(0.0)	15	(0.1)	12	(0.1)	0	(0.0)
E. craigi/caledonense complex°°	29	(0.1)	179	(1.1)	191	(1.5)	30	(44.1)
S. tuberosum	126	(0.4)	0	(0.0)	4	(0.0)	0	(0.0)
S. corbis	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
S. decorum	60	(0.2)	0	(0.0)	84	(0.6)	0	(0.0)
E. aureum	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
E. canonicolum †	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. croxtoni***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. euryadminiculum***	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
E. furculatum	0	(0.0)	0	(0.0)	0	(0.0)	1	(1.5)
*E. excisum*** ††	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
*E. aestivum*** †††	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Pooled abundance per site	31294		16788		12973		68	
Pooled abundance per region	61123							
Adjusted pooled abundance per site	31294		16788		12973		68	
Adjusted pooled abundance per region	61123							

Notes:
° *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
°° voucher specimens identified by P. H. Adler as *Simulium caledonense*.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
††† voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.

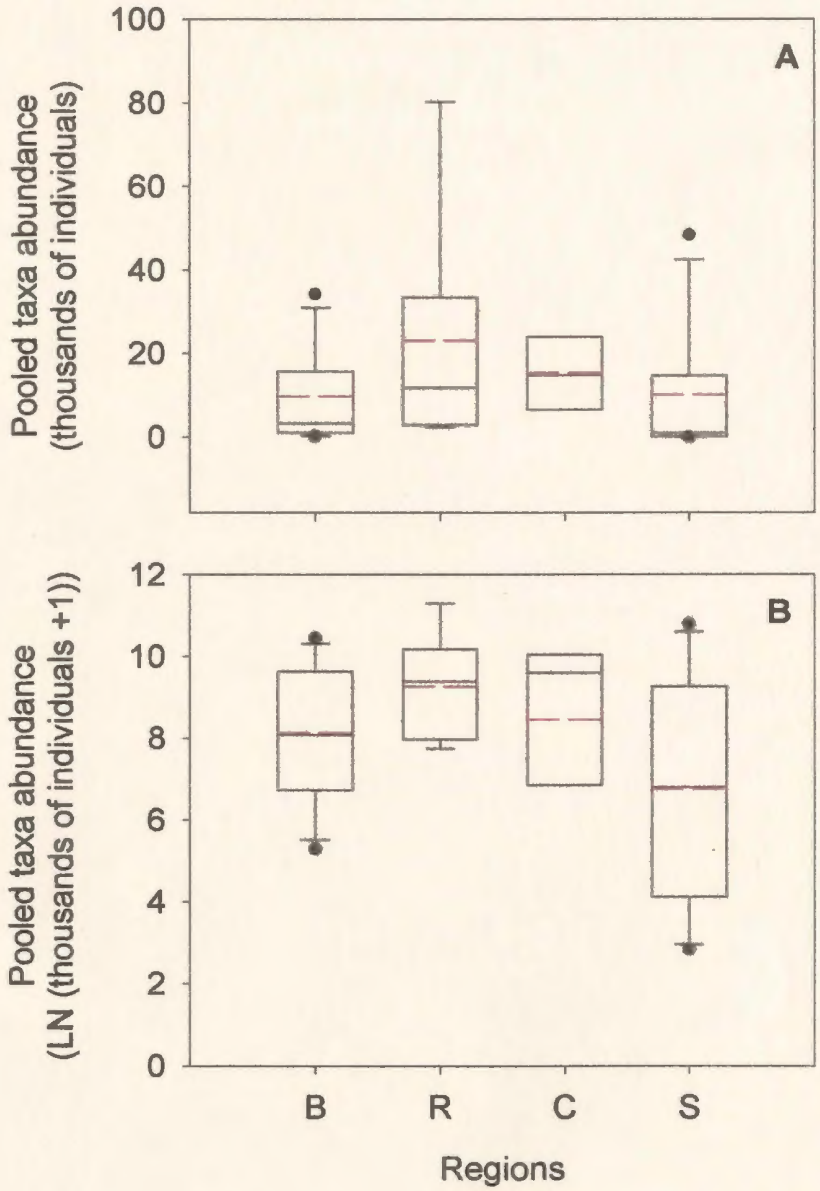


Figure 8. Boxplots of the two-year pooled simuliid taxa abundance data from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S). The mean values per region (--) are not equal to the median values per region (-). Figure 8 uses the pooled taxa abundance per site data from Table 7.

Table 8. One-way ANOVA and Tukey's pairwise comparison results testing for significant final-larval instar head capsule size differences among *P. mixtum/fuscum* complex *S. vittatum*, and *St. mutata* collected in May 1997.

Taxa	n	Head capsule measurements (mm)
		HCL ± SD**
P. mixtum/fuscum complex	166	0.655 ± 0.046 A
S. vittatum	144	0.721 ± 0.038 B
St. mutata	221	0.636 ± 0.042 C
		CAW ± SD**
P. mixtum/fuscum complex	166	0.464 ± 0.030 A
S. vittatum	144	0.546 ± 0.041 B
St. mutata	221	0.512 ± 0.030 C
		ABW ± SD**
P. mixtum/fuscum complex	166	0.375 ± 0.042 A
S. vittatum	144	0.483 ± 0.048 B
St. mutata	221	0.407 ± 0.031 C

** $\alpha < 0.01$ and **different letters** = significant size differences

An one-way ANOVA and Tukey's pairwise comparison showed regional differences in mean head capsule sizes of *P. mixtum/fuscum*, *S. vittatum*, and *St. mutata* (Table 9). *Prosimulium mixtum/fuscum* final-larval instars from St. John's were significantly larger than larvae from Bonavista, Come-by-Chance, and Random Island. Random Island had the smallest *P. mixtum/fuscum* larvae. *Stegopterna mutata* final-larval instars from St. John's were significantly larger than larvae from Random Island, Bonavista, and Come-by-Chance. Come-by-Chance had the smallest *St. mutata* larvae. The longest and widest *S. vittatum* final-larval instars were measured from Come-by-Chance.

3.2. Site Results of the Environmental and Biological Data Using Univariate Statistics

Site differences in the environmental and biological data were expected because the sites were affected by various levels of urbanisation, especially in the St. John's sites. The non-parametric Kruskal-Wallis tests were used instead of parametric one-way ANOVAs to determine mean site-ranked differences in the chemical and physical environmental, pooled taxa richness and taxa abundance, and final-larval instar head capsule data because the residuals of the data were not normally distributed even after a Ln(x+1)-transformation.

Table 9. One-way ANOVA and Tukey's pairwise comparison of head capsule measurements. Results indicate some regional differences in head capsule length (HCL), cephalic apotome width (CAW), and antennal buttress width (ABW) from three simuliid taxa. The results of the statistical analysis for *P. mixtum/ fuscum* complex should be interpreted with caution as the comparison may not be statistically valid as there were only two larvae collected from Come-by-Chance in May 1997.

Taxa	Regions	n	Head capsule measurements (mm)
			HCL ± SD**
P. mixtum/fuscum complex	Bonavista	77	0.644 ± 0.044 ^{A}
	Random Island	54	0.638 ± 0.028 ^{A}
	Come-by-Chance	2	0.658 ± 0.035 ^{AB}
	St. John's	33	0.708 ± 0.037 ^{AB}
			CAW ± SD**
	Bonavista	77	0.466 ± 0.028 ^{A}
	Random Island	54	0.447 ± 0.021 ^{B}
	Come-by-Chance	2	0.467 ± 0.000 ^{ABC}
	St. John's	33	0.484 ± 0.031 ^{C}
			ABW ± SD**
	Bonavista	77	0.388 ± 0.052 ^{A}
	Random Island	54	0.353 ± 0.023 ^{BC}
	Come-by-Chance	2	0.350 ± 0.024 ^{ABC}
	St. John's	33	0.380 ± 0.018 ^{AC}
			HCL ± SD**
S. vittatum	Bonavista	95	0.711 ± 0.035 ^{A}
	Random Island	5	0.720 ± 0.056 ^{AB}
	Come-by-Chance	37	0.746 ± 0.033 ^{B}
	St. John's	7	0.729 ± 0.036 ^{AB}
			CAW ± SD
	Bonavista	95	0.547 ± 0.040 ^{A}
	Random Island	5	0.533 ± 0.053 ^{A}
	Come-by-Chance	37	0.552 ± 0.041 ^{A}
	St. John's	7	0.524 ± 0.043 ^{A}
			ABW ± SD**
	Bonavista	95	0.500 ± 0.042 ^{A}
	Random Island	5	0.413 ± 0.045 ^{B}
	Come-by-Chance	37	0.458 ± 0.040 ^{B}
	St. John's	7	0.445 ± 0.032 ^{B}

** $\alpha < 0.01$ and **different letters** = significant regional size differences

Table 9. (Continued)

Taxa	Regions	n	Head capsule measurements (mm)
			HCL ± SD**
St. mutata	Bonavista	67	0.611 ± 0.043 A
	Random Island	87	0.639 ± 0.030 B
	Come-by-Chance	12	0.600 ± 0.038 A
	St. John's	55	0.668 ± 0.030 C
			CAW ± SD**
	Bonavista	67	0.491 ± 0.025 A
	Random Island	87	0.518 ± 0.027 B
	Come-by-Chance	12	0.485 ± 0.018 A
	St. John's	55	0.532 ± 0.022 C
			ABW ± SD**
	Bonavista	67	0.414 ± 0.036 A
	Random Island	87	0.396 ± 0.025 B
	Come-by-Chance	12	0.376 ± 0.021 B
	St. John's	55	0.421 ± 0.025 A

** $\alpha < 0.01$ and **different letters** = significant regional size differences

3.2.1. *Site chemical data*

The Kruskal-Wallis test showed significant mean site-ranked differences in conductivity, pH, and concentrations of Mg^{2+}, Al^{3+}, Ca^{2+}, K^{+}, and Na^{+} (Table 10). The mean site values were used because they were representative of the data collected over the study period since their means were equal to their median values, except for SO_4^{2-} concentration whose May 1995 values were two orders of magnitude higher than the other SO_4^{2-} values (Table 3). However, the mean SO_4^{2-} values were still used because the study was only interested in the relative effects of the environmental variables on the simuliid assemblage rather than the absolute effects.

For conductivity ($p = 0.000$, df = 22), the St. John's sites had the higher mean values than the sites from Random Island, Bonavista, and Come-by-Chance. S24 had the highest mean value and C14 had the lowest mean value; the remaining sites had mean values within this range (Table 3). For pH ($p = 0.000$, df = 22), Random Island sites had higher mean values than St. John's, Come-by-Chance, and Bonavista. B2, B3, B7, and C14 had a mean pH ≤ 5.9, and the remainder had a mean pH ≥ 6.2. For concentrations of Ca^{2+} ($p = 0.002$, df = 22) and K^{+} ($p = 0.032$, df = 22), St. John's sites had higher mean values than sites from Random Island, Come-by-Chance, and Bonavista. S24 had the highest mean value and B2 and B8 had the lowest mean value. For concentration of Na^{+} ($p = 0.003$, df = 22), St. John's sites had higher mean values than sites from Bonavista, Random Island, and

Table 10. Kruskal-Wallis results testing for significant site differences in 21 environmental variables, taxa richness, and taxa abundance of simuliids. The Kruskal-Wallis results are adjusted for tied ranks.

	Adjusted Kruskal-Wallis	df	Adjusted *p*-value	
Conductivity	90.51	22	0.000	**
pH	56.22	22	0.000	**
SO_4^{2-}	18.73	22	ns	
Mg^{2+}	53.67	22	0.000	**
Zn^{2+}	37.98	22	0.018	*
Al^{3+}	49.52	22	0.000	**
Ca^{2+}	66.23	22	0.000	**
K^{+}	51.98	22	0.000	**
Na^{+}	55.78	22	0.000	**
Cu^{2+}	12.85	22	ns	
TOS	14.00	14	ns	
TIS	14.00	14	ns	
Immediate cover score	22.00	22	ns	
Proximate cover score	22.00	22	ns	
Aquatic vegetation score	22.00	22	ns	
Substrate score	22.00	22	ns	
Stream order	22.00	22	ns	
Stream width	22.00	22	ns	
Physical disturbance score	22.00	22	ns	
Taxa richness	54.76	22	0.000	**
Taxa abundance	43.18	22	0.004	**

* $\alpha < 0.05$, ** $\alpha < 0.01$, and **ns** not significant

Come-by-Chance. S24 had the highest mean value and R19 had the lowest mean value. For concentrations of Mg^{2+} ($p = 0.014$, df = 22), the St. John's sites had higher mean values than sites from Random Island, Bonavista, and Come-by-Chance. S24 had the highest mean value and R13, C14, and C16 had the lowest mean values. S25 and S26 had higher mean values than the other sites, but were lower than S24. For concentration of Al^{3+} ($p = 0.024$, df = 22), the Bonavista sites had higher mean values than Come-by-Chance, St. John's, and Random Island. B7 had the highest mean value and R11 and R19 had the lowest mean value.

The Kruskal-Wallis test showed no significant mean site differences in the mean concentrations of SO_4^{2-}, Zn^{2+}, and Cu^{2+}, and no significant site differences in TOS, and TIS (Table 10). The lack of significant differences was due to the large site variances in the data for these five chemical variables.

3.2.2. *Site physical data*

The Kruskal-Wallis test showed no statistically significant site differences in the scores for immediate cover, proximate cover, aquatic vegetation, substrate, stream order, physical disturbance, or the measurement of stream width (Table 10). The reported *p*-values were adjusted for ties in the ranking procedure of the Kruskal-Wallis test. However, there were marginal differences in the physical variables that might have an effect on the biological data (Table 5). The 23 sites ranged from first-

order to fourth-order streams and had comparable upstream pond areas. Their current velocities were moderate except for C14 and S24 which were below, and R13, S23, and S25 which were above the overall average of 0.50 m/s. Most of the Bonavista and Come-by-Chance sites were open with very little immediate cover over the stream, while the Random Island and St. John's sites ranged from open to covered by a canopy. Most of the sites had very little aquatic vascular vegetation growth, except for B1, B3, C14, and S25. C15 and S23 had dense filamentous algal growth covering the substrates. There were marginal physical disturbance score differences among the 23 sites in that the Random Island sites had the highest disturbance scores compared to the Come-by-Chance sites which had the lowest disturbance scores. B1 and S21 had the same high disturbance score as R11 whereas C15 and C17 had the same low disturbance score. These marginal physical variable differences, although not statistically significant, might affect the pooled taxa richness, pooled taxa abundance, and final-instar head capsule size of simuliids which is examined in the following section.

3.2.3. *Site taxa richness and taxa abundance*

Taxa richness and taxa abundance were examined for site differences that might eventually be correlated to the environmental conditions of a site (Table 10). Taxa richness and taxa abundance were pooled instead of averaged because the

mean value per site was not equal to the median value per site, indicating that the distributions were not normal (Figures 9 and 10).

The Kruskal-Wallis test showed significant site differences in the pooled taxa richness (p = 0.000, df = 22) (Table 10). S22 was the richest site with 14 taxa present of the 16 morphologically identified simuliids, whereas S21, S23, and S24 were the poorest sites with only two taxa present at each site (Table 6). Six of the 16 taxa occurred in at least half of the sites sampled. *Simulium venustum/verecundum* complex (Say, Stone and Jamnback) was present in all 23 sites, *S. vittatum* at 20 sites, *St. mutata* at 19 sites, *Eusimulium craigi/caledonense* complex (Adler and Currie) and *P. mixtum/fuscum* complex at 16 sites, and *Simulium decorum* (Walker) at 12 sites. *Cnephia ornithophilia* and *Eusimulium aureum* (Fries) were present at 7 sites. *Simulium corbis* (Twinn) and *Eusimulium furculatum* (Shewell) were present at 3 sites. *Eusimulium croxtoni* (Nicholson and Mickel), *Eusimulium euryadminiculum* (Davies), *Eusimulium excisum* (Davies, Peterson, and Wood), and *Eusimulium aestivum* (Davies, Peterson, and Wood) were considered rare as they were present at ≤ 2 of 23 sites.

The Kruskal-Wallis test also showed significant site differences in the pooled taxa abundance (p = 0.004, df = 22) (Table 10). Simuliids were most abundant in R19, but scarce in S21 and S23, and several taxa were abundant in this

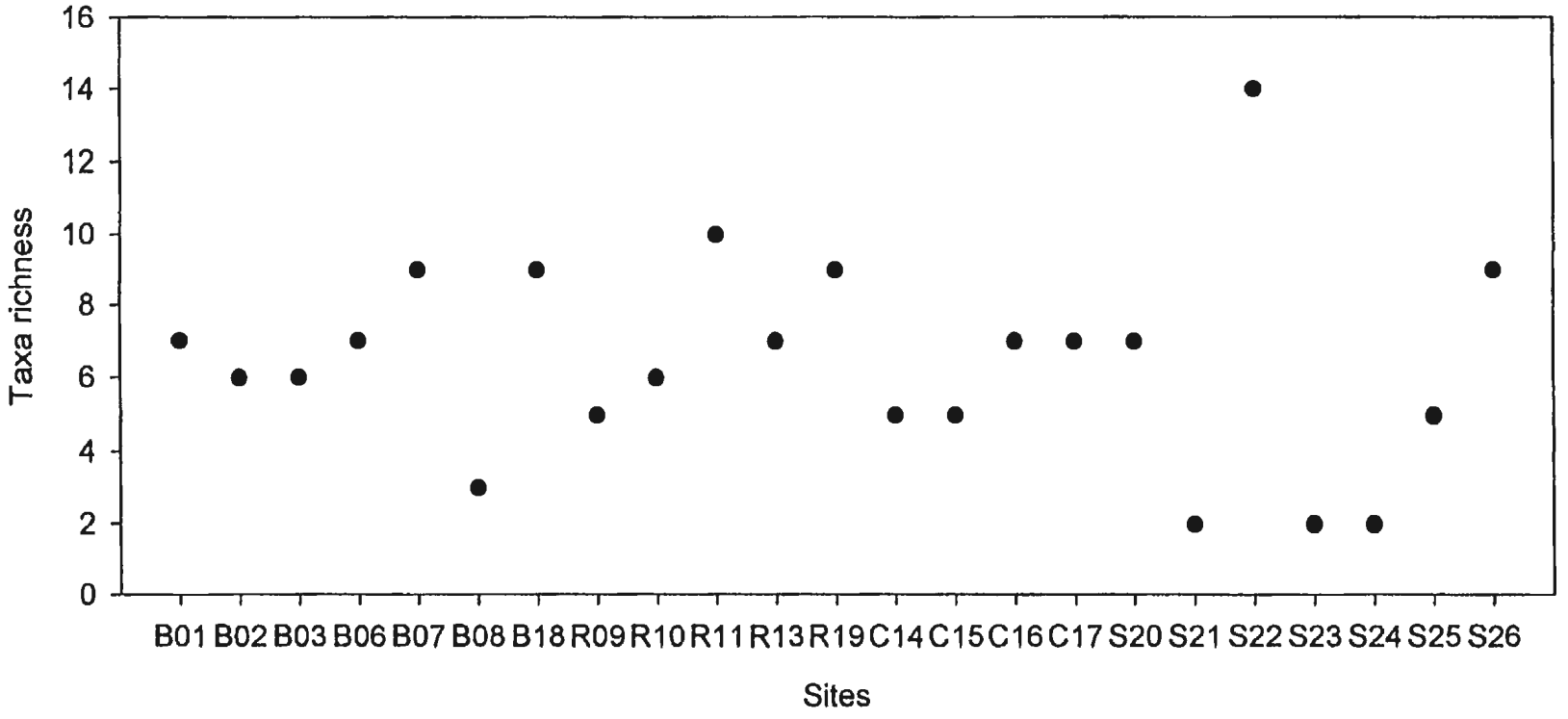


Figure 9. Scatter plot of the two-year pooled simuliid taxa richness data from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S). Figure 9 uses the pooled taxa richness per site data, not adjusted for the mis-identified taxa, from Table 6.

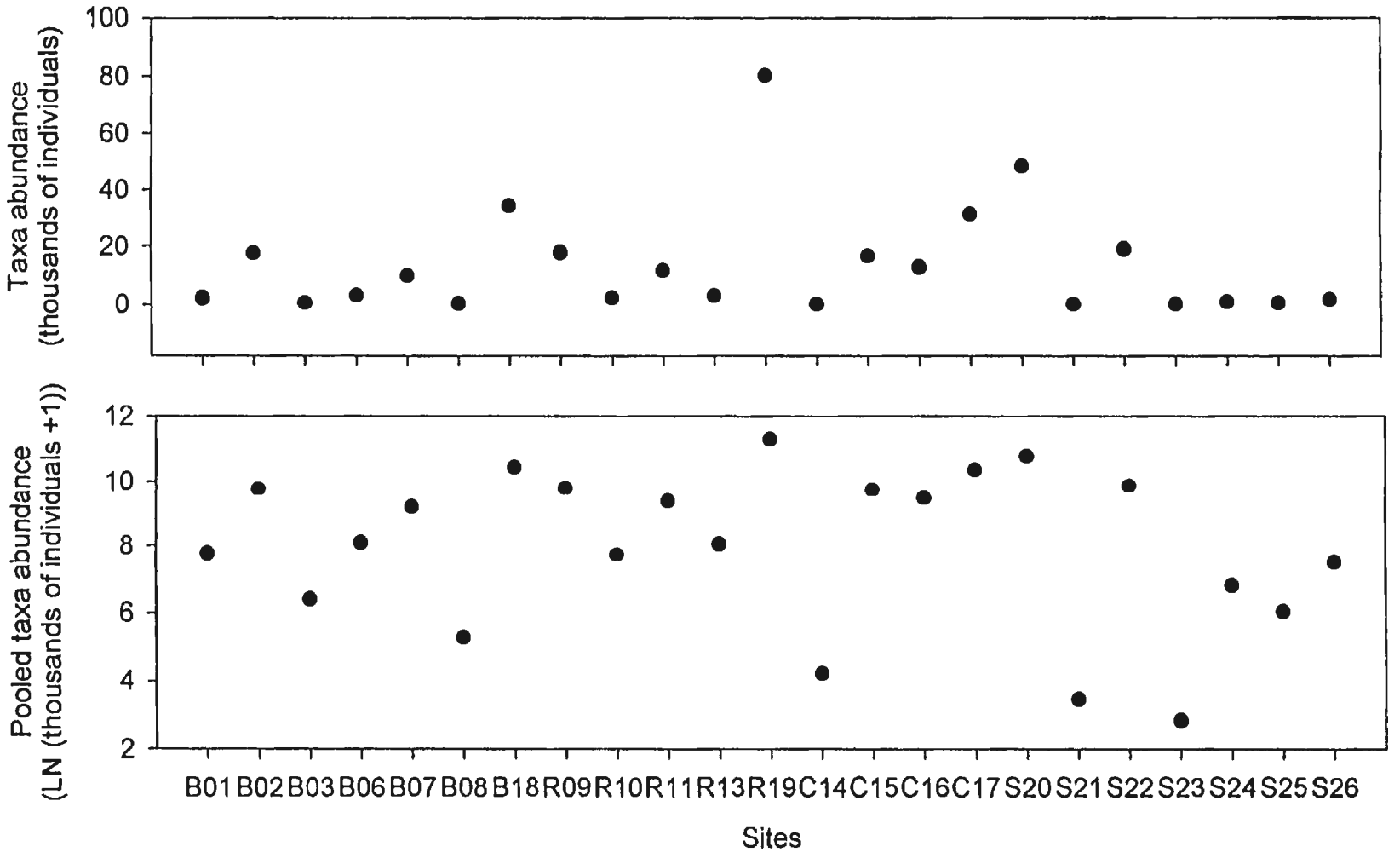


Figure 10. Scatter plots of the two-year pooled simuliid taxa abundance data from Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S). Figure 10 uses the pooled taxa abundance per site data from Table 7.

study (Table 7). *Simulium venustum/verecundum* complex was the most abundant taxa, with one site from each region contributing substantially to the taxon's total numbers. There were more total *St. mutata* than *S. vittatum*, but fewer compared to *S. venustum/ verecundum*. *Cnephia ornithophilia, P. mixtum/fuscum, E. craigi/caledonense, and S. tuberosum* were also abundant, but had considerably fewer individuals than the previous three taxa. Decreasing *C. ornithophilia* abundance is listed in terms of their site occurrence: S22 > B18 > R19 > B7 > B1 > B2 > B3. Decreasing *S. corbis* abundance is also listed in terms of their site occurrence: R13 > S25 > R9. Few individuals belonging to *E. croxtoni*, *E. euryadminiculum*, *E. excisum*, and *E. aestivum* were collected from the 23 sites, except in S22 where they were relatively numerous.

3.2.4. *Site head capsule sizes of three simuliid taxa*

Final-larval instar head capsule sizes were examined for site differences using scatter plots and standard deviations around the mean head capsule measurements per site. Final-larval instars with smaller sized mean head capsules were measured in third and fourth order sites located near the estuary of a watershed (Table 11; Figures 11, 12, and 13). There was no consistent size pattern in final-larval instars from first and second order sites because some sites had large while others had small larvae. In Bonavista, smaller sized *P.mixtum/fuscum*, *S. vittatum, and*

Table 11. Mean head capsule measurements of final-larval instar *P. mixtum/fuscum*, *S. vittatum*, and *St. mutata* collected in May 1997. Sites grouped by region and increasing stream order within a region.

Taxa	Sites	n	Stream order	Head capsule measurements (mm)		
				HCL ± SD	CAW ± SD	ABW ± SD
P. mixtum/fuscum complex	B18	21	First	0.649 ± 0.034	0.460 ± 0.026	0.330 ± 0.028
	B3	20	Second	0.648 ± 0.057	0.465 ± 0.030	0.398 ± 0.030
	B7	16	Third	0.662 ± 0.040	0.479 ± 0.027	0.442 ± 0.048
	B2	2	Third	0.600 ± 0.000	0.450 ± 0.024	0.383 ± 0.024
	B1	18	Third	0.620 ± 0.030	0.467 ± 0.030	0.398 ± 0.033
	R19	21	First	0.639 ± 0.025	0.440 ± 0.023	0.345 ± 0.015
	R9	4	First	0.625 ± 0.017	0.450 ± 0.019	0.358 ± 0.017
	R10	4	First	0.638 ± 0.021	0.458 ± 0.017	0.358 ± 0.017
	R11	13	Second	0.620 ± 0.026	0.445 ± 0.021	0.363 ± 0.037
	R13	12	Fourth	0.658 ± 0.029	0.456 ± 0.016	0.354 ± 0.018
	S20	12	First	0.689 ± 0.019	0.467 ± 0.028	0.375 ± 0.019
	S22	20	First	0.724 ± 0.030	0.492 ± 0.028	0.382 ± 0.017
S. vittatum	B8	16	First	0.702 ± 0.035	0.525 ± 0.034	0.488 ± 0.035
	B18	1	First	0.667 ± 0.000	0.467 ± 0.000	0.400 ± 0.000
	B6	10	First	0.740 ± 0.041	0.567 ± 0.047	0.520 ± 0.039
	B3	1	Second	0.733 ± 0.000	0.500 ± 0.000	0.467 ± 0.000
	B7	18	Third	0.728 ± 0.021	0.550 ± 0.024	0.523 ± 0.034
	B2	30	Third	0.704 ± 0.037	0.550 ± 0.046	0.490 ± 0.044
	B1	19	Third	0.700 ± 0.029	0.553 ± 0.032	0.499 ± 0.042
	C14	11	First	0.730 ± 0.021	0.509 ± 0.020	0.418 ± 0.017
	C16	25	Second	0.756 ± 0.032	0.573 ± 0.030	0.478 ± 0.031
	C15	1	Second	0.667 ± 0.000	0.500 ± 0.000	0.400 ± 0.000
	S20	7	First	0.729 ± 0.036	0.524 ± 0.043	0.445 ± 0.032
St. mutata	B8	3	First	0.678 ± 0.054	0.528 ± 0.025	0.450 ± 0.029
	B18	22	First	0.608 ± 0.044	0.489 ± 0.028	0.376 ± 0.018
	B6	1	First	0.600 ± 0.000	0.500 ± 0.000	0.400 ± 0.000
	B3	4	Second	0.550 ± 0.043	0.450 ± 0.019	0.408 ± 0.017
	B7	29	Third	0.618 ± 0.026	0.494 ± 0.016	0.439 ± 0.024
	B2	6	Third	0.611 ± 0.062	0.497 ± 0.022	0.422 ± 0.034
	B1	2	Third	0.567 ± 0.000	0.483 ± 0.024	0.417 ± 0.024
	R19	20	First	0.648 ± 0.020	0.523 ± 0.018	0.411 ± 0.016
	R9	22	First	0.626 ± 0.033	0.513 ± 0.025	0.383 ± 0.025
	R10	28	First	0.646 ± 0.031	0.525 ± 0.022	0.401 ± 0.023
	R11	15	Second	0.639 ± 0.027	0.509 ± 0.042	0.387 ± 0.028
	R13	2	Third	0.617 ± 0.024	0.500 ± 0.000	0.383 ± 0.024
	S20	40	First	0.680 ± 0.020	0.540 ± 0.017	0.425 ± 0.022
	S22	12	First	0.628 ± 0.023	0.504 ± 0.019	0.397 ± 0.020

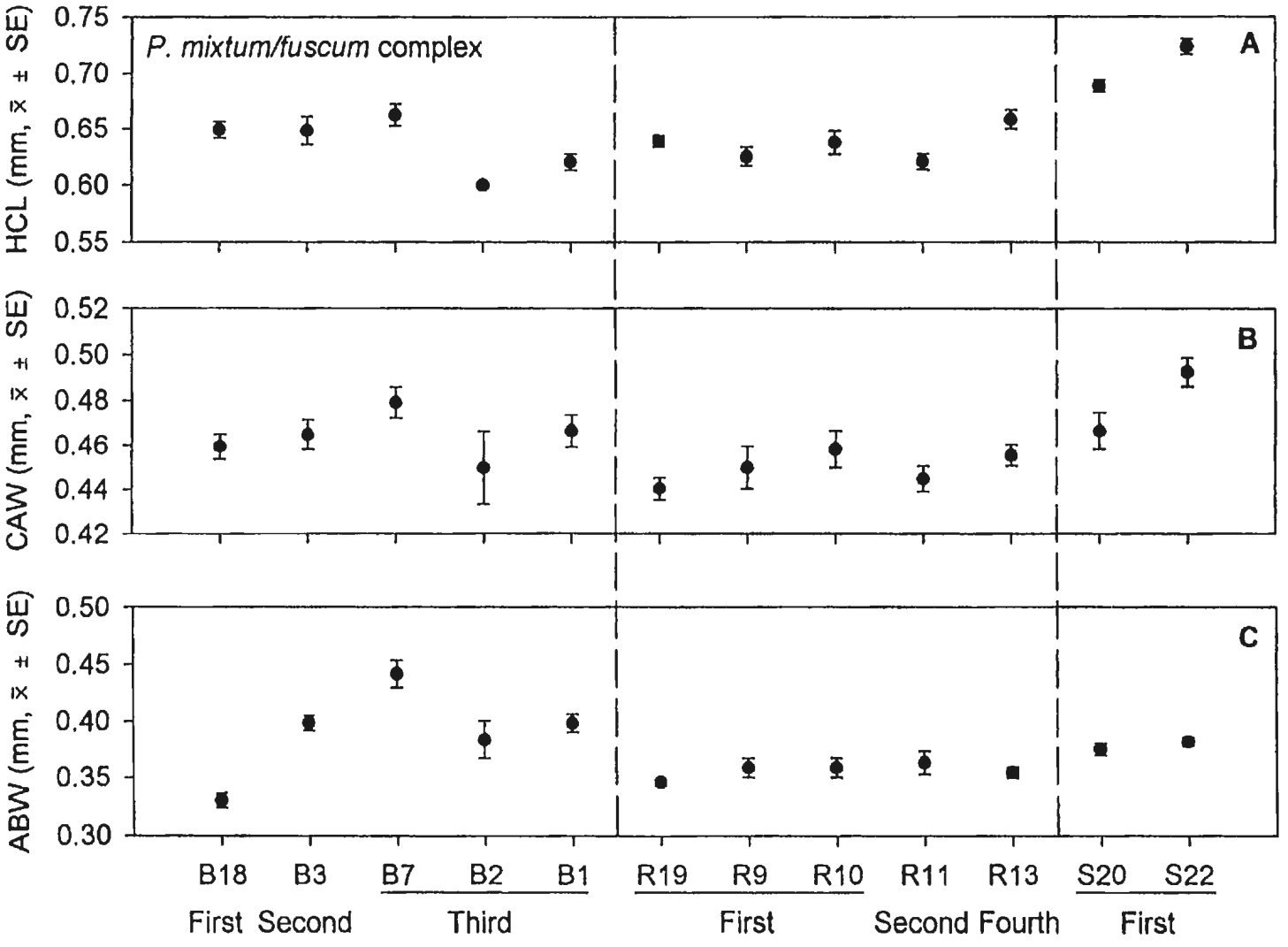


Figure 11. Final larval-instar *P. mixtum/fuscum* complex head capsule measurements. Sites in Bonavista (B), Random Island (R), and St. John's (S) are arranged by increasing stream order. Sites lower in a watershed generally had smaller final-larval instars.

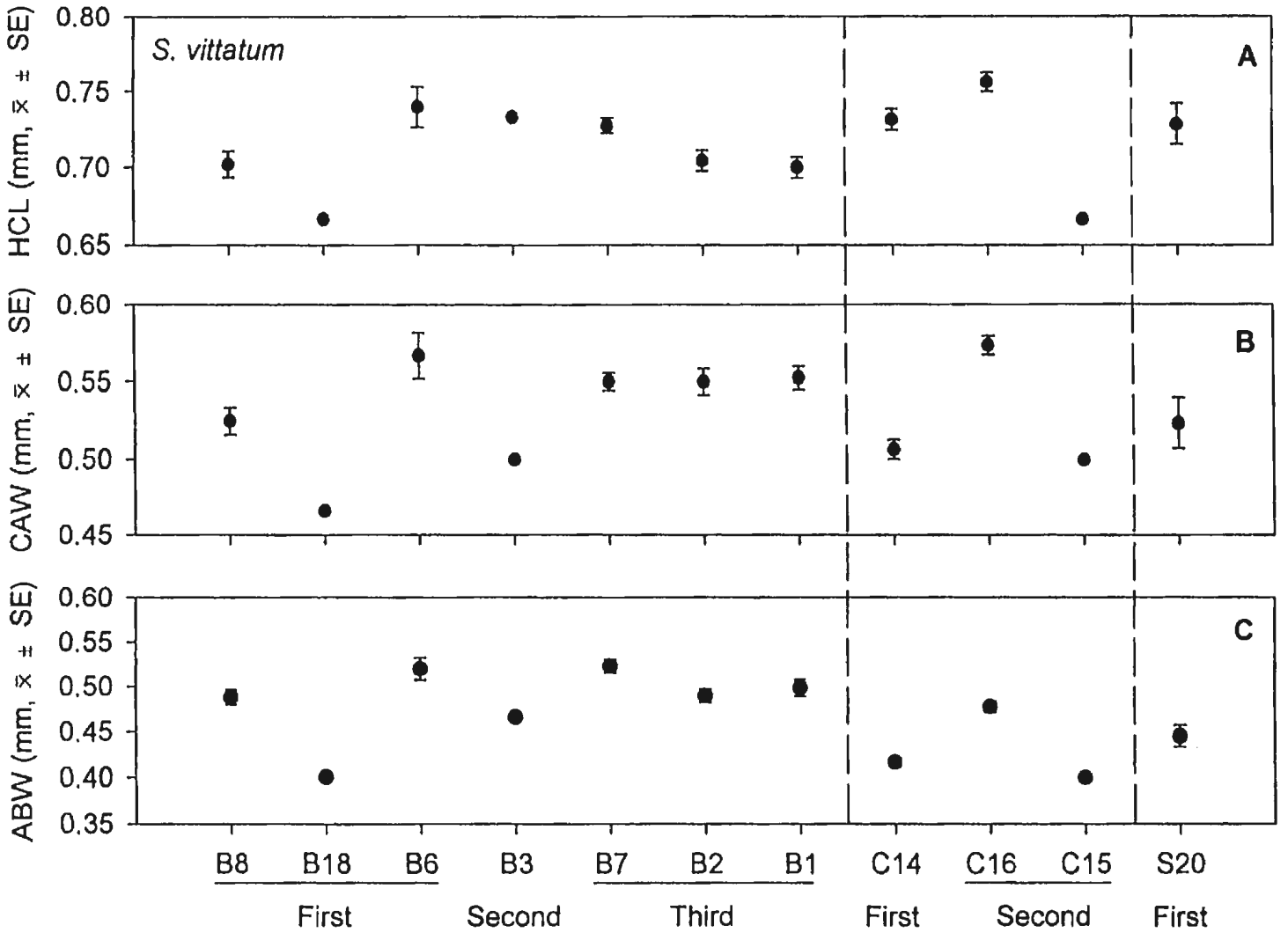


Figure 12. Final larval-instar *S. vittatum* head capsule measurements. Sites in Bonavista (B), Come-by-Chance (C), and St. John's (S) are arranged by increasing stream order. Sites lower in a watershed generally had smaller final-larval instars.

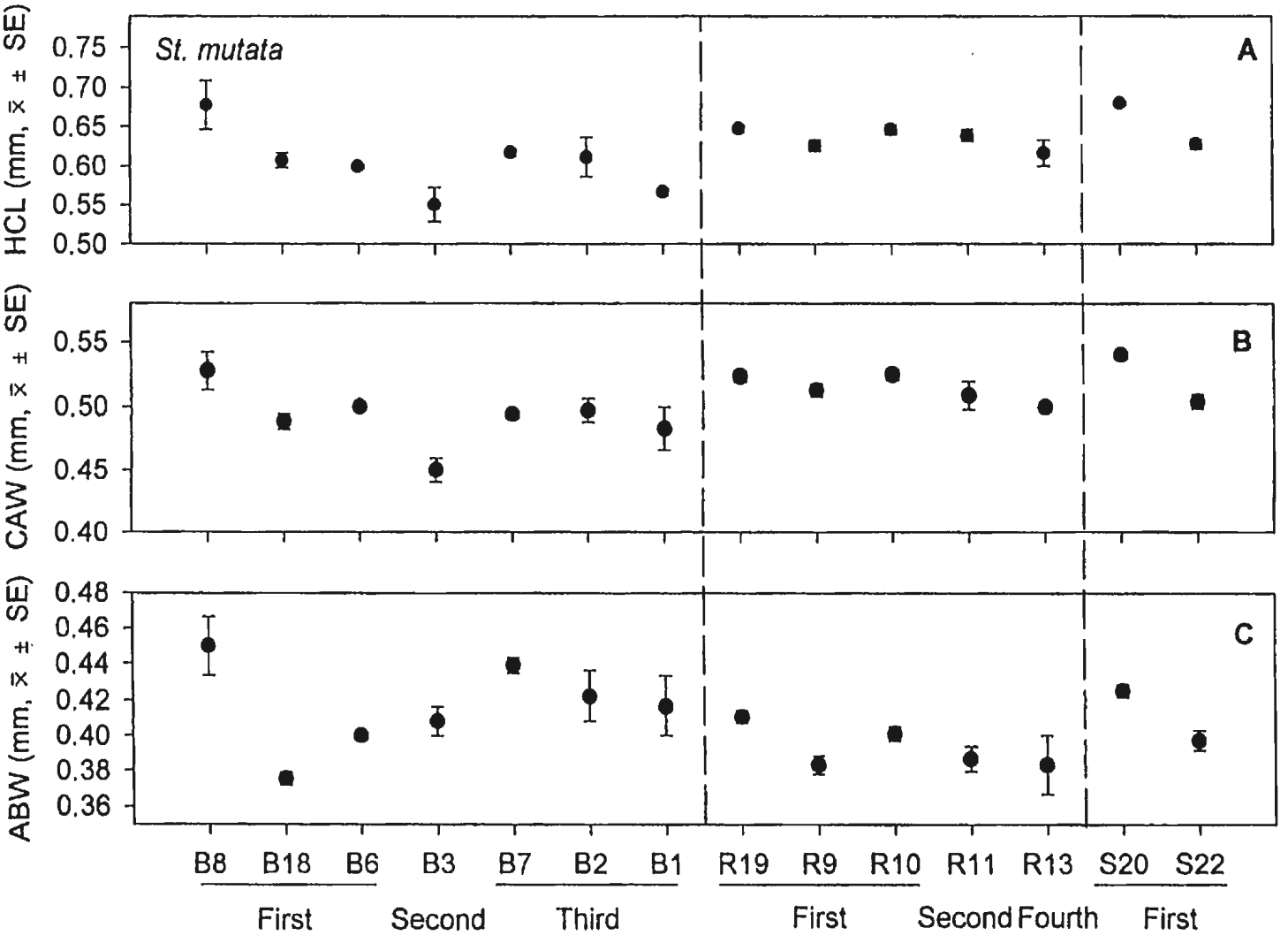


Figure 13. Final larval-instar *St. mutata* head capsule measurements. Sites in Bonavista (B), Random Island (R), and St. John's (S) are arranged by increasing stream order. Sites lower in a watershed generally had smaller final-larval instars.

St. mutata larvae were measured in B1 compared to larvae from B2 and B7. On Random Island, the decreasing size pattern was also observed in *St. mutata*, but not in *P. mixtum/fuscum* larvae. In Come-by-Chance, C15 had smaller sized *S. vittatum* larvae than C16. There were no final-larval instars collected from the higher stream-order sites in St. John's, making it impossible to determine if the decreasing size pattern also existed in the St. John's sites.

3.3. Spearman's Correlation Results of the Environmental and Biological Data Univariate Analyses

The non-parametric Spearman's correlation was used because the residuals of the environmental and biological data were not normally distributed and all the physical variables as well as the pooled taxa richness and taxa abundance were categorical/interval data. Pearson's correlation analysis was used on the final-larval instar head capsule measurements and the five selected chemical variables because they were normal and continuous. The correlation among chemical variables is reported first, followed by the correlation among physical variables, correlation among chemical variables and pooled taxa richness and pooled taxa abundance, among physical variables and pooled taxa richness and pooled taxa abundance, and among four selected chemical variables and final-larval instar head capsule measurements.

3.3.1 *Chemical data*

The Spearman's correlation results showed significant correlations among the chemical environmental data. Conductivity was negatively correlated to SO_4^{2-} and Al^{3+} concentrations (p = 0.043 and 0.006 respectively, df = 258), but positively correlated to the remaining ions, except for Cu^{2+} which was not significantly correlated to conductivity (Table 12A). pH was negatively correlated to SO_4^{2-}, Al^{3+}, and Cu^{2+} concentrations (p = 0.043, 0.006, and 0.010 respectively, df = 258), but positively correlated to the remaining ions, except for Zn^{2+} and Na^{+} which were not significantly correlated to pH. There were also correlations among the ion concentrations.

3.3.2. *Physical data*

The Spearman's correlation results showed significant correlations among several of the physical environmental score data (Table 12B). Immediate cover score was negatively correlated to substrate score and stream width (p = 0.033 and 0.044 respectively, df = 159). Substrate score was positively correlated to stream order score and stream width (p = 0.000 and 0.004 respectively, df = 159). Stream order was significantly positively correlated to stream width (p = 0.000, df = 159).

Table 12A. Spearman correlations (*p*-values) among the measured chemical variables.

	Conductivity	pH	SO_4^{2-}	Mg^{2+}	Zn^{2+}	Al^{3+}	Ca^{2+}	K^+	Na^+	Cu^{2+}	TOS	TIS
Conductivity	-	-	-	-	-	-	-	-	-	-	-	-
pH	0.439 (0.036*)	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	-0.425 (0.043*)	-0.582 (0.004**)	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	0.894 (0.000**)	0.534 (0.009**)	-0.428 (0.042*)	-	-	-	-	-	-	-	-	-
Zn^{2+}	0.434 (0.039*)	ns	ns	ns	-	-	-	-	-	-	-	-
Al^{3+}	-0.560 (0.006**)	-0.796 (0.000**)	0.635 (0.001**)	-0.706 (0.000**)	ns	-	-	-	-	-	-	-
Ca^{2+}	0.573 (0.004**)	0.806 (0.000**)	-0.538 (0.008**)	0.649 (0.001**)	ns	-0.714 (0.000**)	-	-	-	-	-	-
K^+	0.907 (0.000**)	0.581 (0.004**)	-0.462 (0.027*)	0.847 (0.000**)	ns	-0.667 (0.000**)	0.690 (0.000**)	-	-	-	-	-
Na^+	0.975 (0.000**)	ns	ns	0.827 (0.000**)	0.473 (0.022*)	-0.447 (0.032*)	0.463 (0.026*)	0.878 (0.000**)	-	-	-	-
Cu^{2+}	ns	-0.528 (0.010*)	0.674 (0.000**)	ns	ns	0.543 (0.008**)	-0.454 (0.030*)	ns	ns	-	-	-
TOS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	-
TIS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.875 (0.000**)	-

* α < 0.05, ** α < 0.01, and ns not significant (df = n-2 = 258)

Table 12B. Spearman correlations (*p*-values) among the measured physical variables.

	Immediate cover score	Proximate cover score	Aquatic vegetation score	Substrate score	Stream order	Stream width	Physical disturbance score
Immediate cover score	-	-	-	-	-	-	-
Proximate cover score	ns	-	-	-	-	-	-
Aquatic vegetation score	ns	ns	-	-	-	-	-
Substrate score	-0.445 (0.033*)	ns	ns	-	-	-	-
Stream order	ns	ns	ns	0.795 (0.000**)	-	-	-
Stream width	-0.424 (0.044*)	ns	ns	0.582 (0.004**)	0.782 (0.000**)	-	-
Physical disturbance score	ns	ns	ns	ns	ns	ns	-

* $\alpha < 0.05$, ** $\alpha < 0.01$, and **ns** not significant (df = n-2 = 159)

3.3.3. *Environmental data, taxa richness, and taxa abundance*

The Spearman's correlation results showed significant correlations among the chemical environmental and pooled taxa richness and pooled taxa abundance data, irrespective of which of the 16 taxa occurred at a site (Table 12C). Concentrations of SO_4^{2-} and K^+ were negatively correlated to the pooled taxa richness ($p = 0.041$ and 0.037 respectively, df = 159). Concentrations of Zn^{2+} and Cu^{2+} were negatively correlated to the pooled taxa abundance ($p = 0.020$ and 0.027 respectively, df = 159). There were no significant correlations among the physical environmental and the pooled taxa richness and abundance data (Table 12C).

3.3.4. *Environmental data and head capsule sizes*

The Pearson's correlation results showed significant correlations among the final-larval instar head capsule measurements of *P. mixtum/fuscum*, *S. vittatum*, and *St. mutata* (Table 13). For *P. mixtum/fuscum*, the HCL measurement was positively correlated to the CAW and ABW measurements, and the CAW measurement was positively correlated to ABW measurements (p = 0.0001, 0.0013, and 0.0001 respectively, df = 164). For *S. vittatum*, HCL was positively correlated to CAW and ABW, and CAW was positively correlated to ABW (p = 0.0001, 0.0006, and 0.0001 respectively, df = 164). For *St. mutata*, HCL was positively correlated to CAW and ABW, and CAW was positively correlated to ABW (p = 0.0001, 0.0001, and

Table 12C. Spearman correlations (*p*-values) between taxa richness and the measured physical and chemical variables and between taxa abundance and the measured physical and chemical variables.

	Conductivity	pH	SO_4^{2-}	Mg^{2+}	Zn^{2+}	Al^{3+}	Ca^{2+}	K^{+}	Na^{+}	Cu^{2+}
Taxa richness	ns	ns	-0.428 (0.041*)	ns	ns	ns	ns	-0.437 (0.037*)	ns	ns
Taxa abundance	ns	ns	ns	ns	-0.482 (0.020*)	ns	ns	ns	ns	-0.461 (0.027*)

	TOS	TIS
Taxa richness	ns	ns
Taxa abundance	ns	ns

* α < 0.05, ** α < 0.01, and **ns** not significant

df = n-2 = 258 (richness), 258 (abundance)

	Immediate cover score	Proximate cover score	Aquatic vegetation score	Substrate score	Stream order	Stream width	Physical disturbance score
Taxa richness	ns	ns	ns	ns	ns	ns	ns
Taxa abundance	ns	ns	ns	ns	ns	ns	ns

* α < 0.05, ** α < 0.01, and **ns** not significant

df = n-2 = 159 (richness), 159 (abundance)

Table 13. Pearson's correlations among selected environmental variables and the three simuliid head capsule measurements. Values reported are the r, (*p*-value), and α-levels of significance.

P. mixtum/fuscum complex (n = 166; df = n-2 = 164)

	HCL	CAW	ABW
HCL	-	-	-
CAW	0.515 (0.0001**)	-	-
ABW	0.248 (0.0013**)	0.524 (0.0001**)	-
TOS	-0.235 (0.0129*)	-0.209 (0.0275*)	-0.280 (0.0030**)
TIS	ns	ns	-0.200 (0.0353*)
pH	ns	-0.256 (0.0009**)	-0.513 (0.0001**)
Al^{3+}	ns	0.241 (0.0018**)	0.440 (0.0001**)

S. vittatum (n = 166; df = n-2 = 164)

	HCL	CAW	ABW
HCL	-	-	-
CAW	0.544 (0.0001**)	-	-
ABW	0.283 (0.0006**)	0.645 (0.0001**)	-
TOS	ns	ns	-0.276 (0.0081**)
TIS	ns	ns	-0.240 (0.0217*)
pH	ns	ns	-0.187 (0.0217*)
Al^{3+}	0.299 (0.0003**)	0.645 (0.0001**)	0.205 (0.0135*)

St. mutata (n = 166; df = n-2 = 164)

	HCL	CAW	ABW
HCL	-	-	-
CAW	0.746 (0.0001**)	-	-
ABW	0.444 (0.0001**)	0.469 (0.0001**)	-
TOS	ns	ns	-0.213 (0.0055**)
TIS	ns	ns	-0.209 (0.0063**)
pH	0.229 (0.0006**)	0.307 (0.0001**)	-0.370 (0.0001**)
Al^{3+}	-0.329 (0.0001**)	-0.400 (0.0001**)	0.194 (0.0038**)

* $\alpha < 0.05$, ** $\alpha < 0.01$, and **ns** not significant

0.0001 respectively, df = 164).

The Pearson's correlation results also showed significant correlations among the four selected chemical environmental variables and the head capsule measurements of the three taxa (Table 13). For *P. mixtum/fuscum*, the concentration of TOS was negatively correlated to HCL, CAW, and ABW (p = 0.0129, 0.0275, and 0.0030 respectively, df = 164), TIS was negatively correlated to ABW only (p = 0.0353, df = 164), pH was negatively correlated to CAW and ABW (p = 0.0009 and 0.0001 respectively, df = 164). Aluminum cation concentration was positively correlated to CAW and ABW (p = 0.0018 and 0.0001 respectively, df = 164). For *S. vittatum*, TOS and TIS concentrations and pH were negatively correlated to ABW only (p = 0.0081, 0.0217, and 0.0217 respectively, df = 164). Aluminum cation concentration was positively correlated to HCL, CAW, and ABW (p = 0.0003, 0.0001, and 0.0135 respectively, df = 164). For *St. mutata*, TOS and TIS concentrations were negatively correlated to ABW only (p = 0.0055 and 0.0063 respectively, df = 164) and pH was positively correlated to HCL and CAW, but negatively correlated to ABW (p = 0.0009 and 0.0001 respectively, df = 164). Aluminum cation concentration was negatively correlated to HCL and CAW, but positively correlated to ABW (p = 0.0001, 0.0001, and 0.0038 respectively, df = 164).

The results of the Spearman's and Pearson's correlation analyses showed that the chemical environmental variables were significantly correlated with each other as

well as certain chemical variables were significantly correlated to the pooled taxa richness and taxa abundance. To a lesser extent, the physical environmental variables were significantly correlated with each other, but not significantly correlated to the pooled taxa richness and taxa abundance of simuliids. Therefore, because of these inter-correlations among variables, a multivariate approach was also used to assess the impacts of the regional and site environmental conditions on the pooled taxa richness and taxa abundance of simuliids.

3.4. Multivariate Analyses of the Environmental and Biological Data

Principal components analysis (PCA), a common exploratory multivariate technique in the literature (Ciborowski and Adler 1990, McCreadie *et al.* 1995, Fore *et al.* 1996), was used in this study to reduce many of the explanatory variables to several significant composite factors. In PCA, the selection of the composite factors was based on eigenvectors > 1.0 that were calculated from a Pearson's correlation matrix, and the variables with correlation coefficients > 0.600 were noted as contributing to the factor's eigenvector and score. This critical correlation coefficient ($r = 0.600$) was selected because the difference between subsequent correlation coefficients < 0.600 were greater than the difference between preceding correlation coefficients > 0.600 in the Pearson's correlation matrix. The Environmental PCA results are reported first using scatter plots of the factor scores, followed by the

adjusted pooled taxa richness and pooled taxa abundance PCA results, and then the Pearson's correlation analysis among the Environmental and Biological PCA results are reported.

3.4.1. *Regional and site environmental PCA*

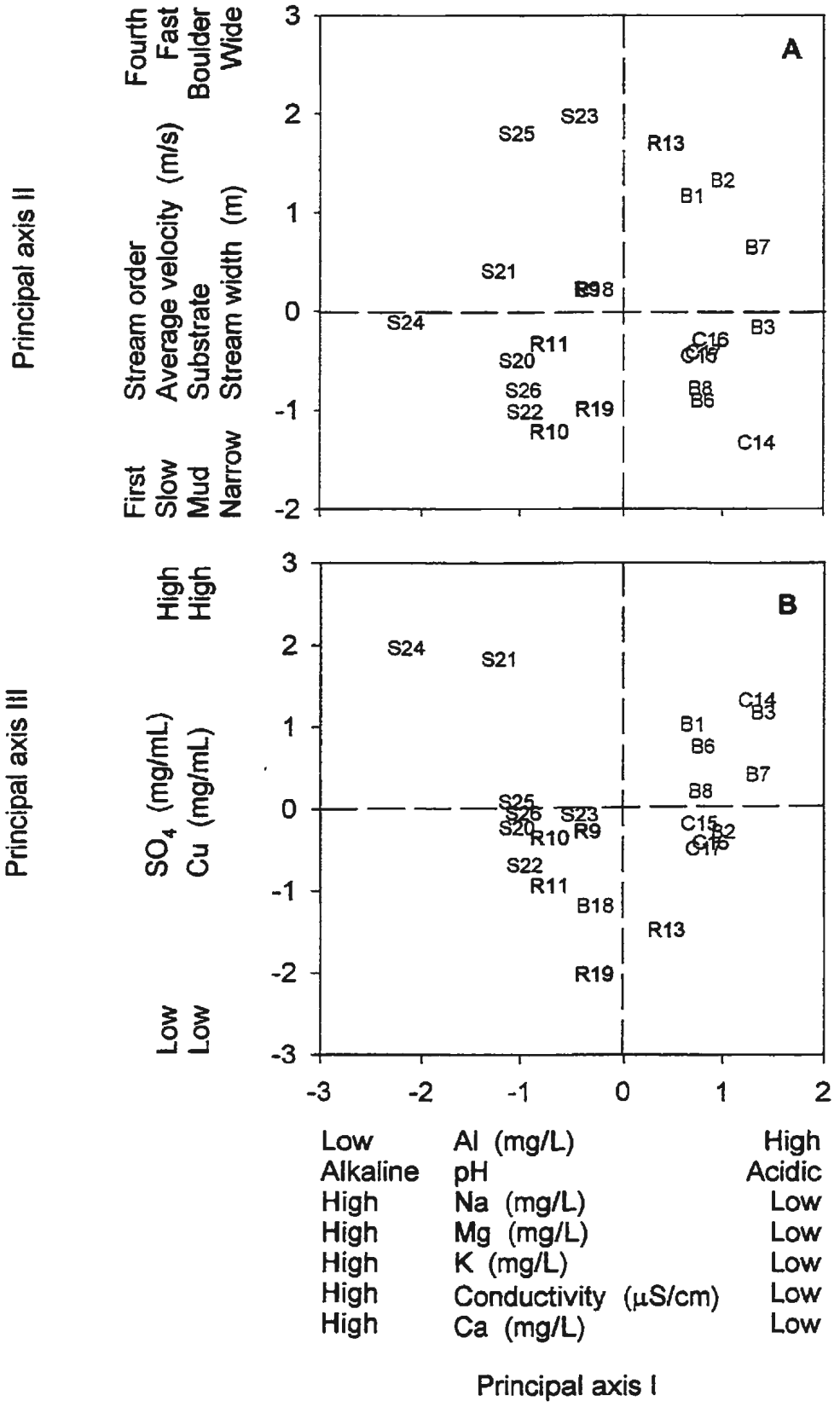
The Environmental PCA results showed that six factors accounted for 81.5% of the variance in the environmental data, but only Factors I, II, III, and V had correlation coefficients greater than 0.6 (Table 14). Note that factors in the context of this research is a synonym of axes. These four factors accounted for 69.3% of the total variance. Factor I was chemical in composition with concentrations of Na^{+}, Mg^{2+}, K^{+}, Ca^{2+}, pH, and conductivity negatively correlated with concentrations of Al^{3+}, but positively correlated with each other. Factor II was physical in composition with stream order, average velocity, substrate type, and stream width positively correlated with each other. Factor III was also chemical in composition with concentrations of SO_4^{2-} and Cu^{2+} positively correlated with each other. Factor V was the physical disturbance score.

Regional and site separation were evident in the scatter plots of most of the environmental factor scores. The four regions separated on Factor I such that St. John's had a low score compared to Random Island, Come-by-Chance, and Bonavista; Bonavista had a high score (Figures 14A and 14B).

Table 14. Prinicpal components analysis results of 19 environmental variables from the 23 sites. Pearson's correlation was used to assess significant correlations among PC-Scores and environmental variables (r, $\alpha < 0.01$). The first six factors explain 81.5 % of the variance within the data. However, only Factors I, II, III, and V had factor loadings > 0.600 and explain 69.3% of the variance in the data.

Principal axes (factors)	Site characteristics and range of values			Interpretation of PC-Axes scores		Correlation among characteristics and PC-Axis Scores	Percent explained variance
		Minimum	Maximum	Low score	High score		
I	Al^{3+} (mg/L)	0.014	0.119	Low	High	0.864	
I	pH	5.556	7.202	Alkaline	Acidic	-0.767	
I	Na^{+} (mg/L)	3.208	109.690	High	Low	-0.780	
I	Mg^{2+} (mg/L)	0.610	2.828	High	Low	-0.837	
I	K^{+} (mg/L)	0.217	2.100	High	Low	-0.843	
I	Conductivity (µS/cm)	31.660	1359.000	High	Low	-0.865	
I	Ca^{2+} (mg/L)	1.019	16.790	High	Low	-0.875	33.5
II	Stream order	1	4	First	Fourth	0.819	
II	Average velocity (m/s)	0.160	0.830	Slow	Fast	0.767	
II	Substrate	1	5	Mud	Boulder	0.732	
II	Stream width (m)	0.680	11.200	Narrow	Wide	0.698	16.8
III	SO_4^{2-} (mg/L)	3.050	42.083	Low	High	0.649	
III	Cu^{2+} (mg/L)	0.002	0.008	Low	High	0.615	12.6
V	Disturbance score	3	9	High	Low	-0.610	6.4
	TOTAL						69.3

Figure 14. PCA regional and site environmental results. Regional and site separation based on inter-correlated chemical and physical environmental variables. Environmental Principal axis or Factor I is chemical, Environmental Principal axis or Factor II is physical (**A**), and Environmental Principal axis or Factor III is chemical (**B**) in characteristics.


Principal axis II
Principal axis III
Principal axis I
A
B
Fourth
Fast
Boulder
Wide
Stream order
Average velocity (m/s)
Substrate
Stream width (m)
First
Slow
Mud
Narrow
High
High
SO_4 (mg/mL)
Cu (mg/mL)
Low
Low
Low Al (mg/L) High
Alkaline pH Acidic
High Na (mg/L) Low
High Mg (mg/L) Low
High K (mg/L) Low
High Conductivity (µS/cm) Low
High Ca (mg/L) Low

Bonavista was more acidic, had lower conductivity, and lower concentrations of Na^{+}, Mg^{2+}, K^{+}, and Ca^{2+}, but higher concentrations of Al^{3+} than St. John's. Random Island and Come-by-Chance had values in the middle of the above extremes. At the site level, the 23 sites also separate from each other on Factor I. The Come-by-Chance sites were grouped with B3, B6, and B8. R10, R11, and R19 were grouped with S20, S22, S24, and S26. S21, S23, and S25 were grouped with R9 and B18. B1, B2, and B7 were grouped with R13 (Figure 14A). A secondary site arrangement had the Come-by-Chance sites grouped with the Bonavista sites, except for B18. The Random Island sites were grouped with B18 and the St. John's sites, except for S21 and S24. S21 and S24 were grouped together (Figure 14B).

The 4 regions and 23 sites did not separate on Factor II, indicating that the regions were comprised of sites with similar physical characteristics and that the 23 sites were representative of a variety of stream types (Figure 14A). The four regions did not separate on Factor III, indicating that the regions had similar concentrations of SO_4^{2-} and Cu^{2+} (Figure 14B). At the site level, S21 and S24 separated from the other sites as they had the highest SO_4^{2-} and Cu^{2+} concentrations. Three of the four regions scored negatively and positively on Factor V; Random Island was the only region to score negatively on Factor V, indicating that Random Island had a

higher physical disturbance score than the other regions (Figures 15A, 15B, and 15C). At the site level, only B2 separated from the other sites as it had the lowest physical disturbance score. Sites from Bonavista, Come-by-Chance, and St. John's had similar physical disturbance scores as the Random Island sites.

3.4.2. *Regional and site taxa richness PCA*

The adjusted pooled taxa richness PCA results showed that the first four axes (factors used synonymously) accounted for 70.4% of the variance in the pooled taxa richness or presence/absence data (Table 15). This adjusted data lacked taxa deemed rare (i.e., present in ≤ 2 sites) and prevalent taxa (i.e., present in all sites). The removal of rare and prevalent taxa focused the analysis on the common taxa and their relationship to their environment. The presence of *Simulium decorum* (Walker), *S. tuberosum*, *Eusimulium canonicolum* (Dyar and Shannon), *St. mutata*, and *P. mixtum/fuscum* were negatively correlated with each other on Factor I. The presence of *E. furculatum*, *S. vittatum*, and *E. craigi/caledonense* (formerly known as *Simulium vernum* (Macquart) complex; modified by Adler and Currie 1986) contributed positively to Factors II, III, and IV respectively. It should be noted that the current analysis is "an investigation of community structure and not one of taxa richness in the traditional sense of the word". Ludwig and Reynolds (1988) refer to this type of analysis as a r-strategy ordination of community structure.

Figure 15. PCA regional and site environmental results. Regional and site separation based on inter-correlated chemical and physical environmental variables on Environmental Principal axis or Factor V and Factor I (**A**). No regional and site separation based on Factor V and Factors II (**B**) and III (**C**). Factor V is the physical disturbance score, Factor I is chemical, and Factor III is chemical in characteristics.

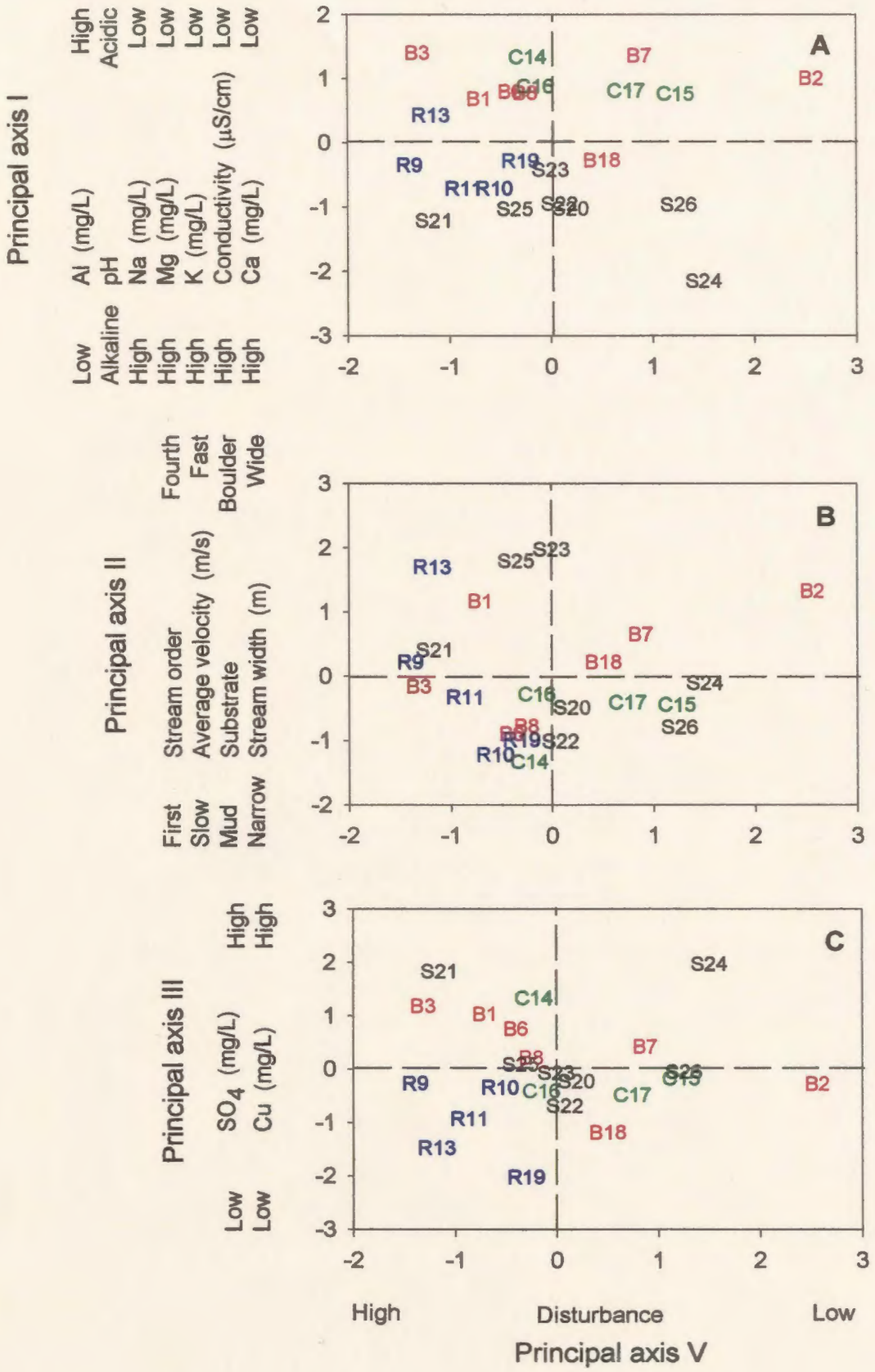

Principal axis I
Low Alkaline
High
High
High
High
High
Al (mg/L)
pH
Na (mg/L)
Mg (mg/L)
K (mg/L)
Conductivity (µS/cm)
Ca (mg/L)
High Acidic
Low
Low
Low
Low
Low
A
B3
C14
B7
B2
B1
C16
C17
C15
R13
R9
R19
S23
B18
R1
R10
S25
S20
S26
S21
S24
Principal axis II
First
Slow
Mud
Narrow
Stream order
Average velocity (m/s)
Substrate
Stream width (m)
Fourth
Fast
Boulder
Wide
B
S25
S23
R13
B2
B1
B7
S21
R9
B18
S24
B3
R11
C16
S20
C17
C15
S26
R10
C14
S22
Principal axis III
Low
Low
SO4 (mg/L)
Cu (mg/L)
High
High
C
S21
S24
B3
C14
B1
B6
B7
R9
R10
C16
S20
C17
B2
S22
R11
B18
R13
R19
High
Disturbance
Low
Principal axis V

Table 15. Principal components analysis of the adjusted pooled presence/absence of 11 simuliid taxa from the 23 sites. Rare taxa were removed from the analysis. Pearson's correlation was used to assess significant correlations among PC-Scores and presence/absence (r, $\alpha < 0.01$). The first four factors explain 70.4 % of the variance within the data.

Principal axes (factors)	Simuliid taxa and range of values			Interpretation of PC-Axes scores		Correlation among taxa and PC-Axes scores	Percent explained variance
		Minimum	Maximum	Low score	High score		
I	*S. decorum*	0	1	Present	Absent	-0.620	
I	*S. tuberosum*	0	1	Present	Absent	-0.674	
I	*E. canonicolum*	0	1	Present	Absent	-0.687	
I	*St. mutata*	0	1	Present	Absent	-0.715	
I	*P. mixtum/fuscum* complex	0	1	Present	Absent	-0.730	29.1
II	*E. furculatum*	0	1	Absent	Present	0.877	16.3
III	*S. vittatum*	0	1	Absent	Present	0.868	13.7
IV	*E. craigi/caledonense* complex	0	1	Absent	Present	0.610	11.3
Total							70.4

Note: The above results reflect the data with the mis-identified taxa as noted in Tables 6 and 7.

No regional separation was evident in the scatter plot of the pooled taxa richness Principal axis I and II since the sites in a region did not group together on these two factors (Figure 16). At the site level, sites grouped over regions as the same taxon was collected from sites in all regions. R11 and R19 were grouped with B7 and B18. C14, S22, and S26 were grouped together. B1, B2, B3, B6, R10, R13, C15, C16, C17, and S20 were grouped together as were B8, R9, S23, S24, and S25. There were no distinct regional nor site patterns in the remaining taxa richness factor scores.

3.4.3. *Regional and site taxa abundance PCA*

The adjusted pooled taxa abundance PCA results showed that the first five factors accounted for 80.6% of the variance in the pooled taxa abundance data (Table 16).The adjusted data lacked taxa deemed rare (i.e., abundant in $\leq$ 2 sites). The removal of the rare taxa focused the analysis on the most abundant and commonly abundant taxa and their relationship to their environment. Abundances of *P. mixtum/fuscum* complex, *C. ornithophilia*, and *S. tuberosum* were positively correlated with each other, but negatively correlated with abundances of *S. vittatum* on Factor I. Abundances of *E. furculatum* and *E. craigi/caledonense* complex were negatively correlated with *S. venustum/ verecundum* complex on Factor II. Abundance of *S. corbis* contributed positively to Factor III while abundances of

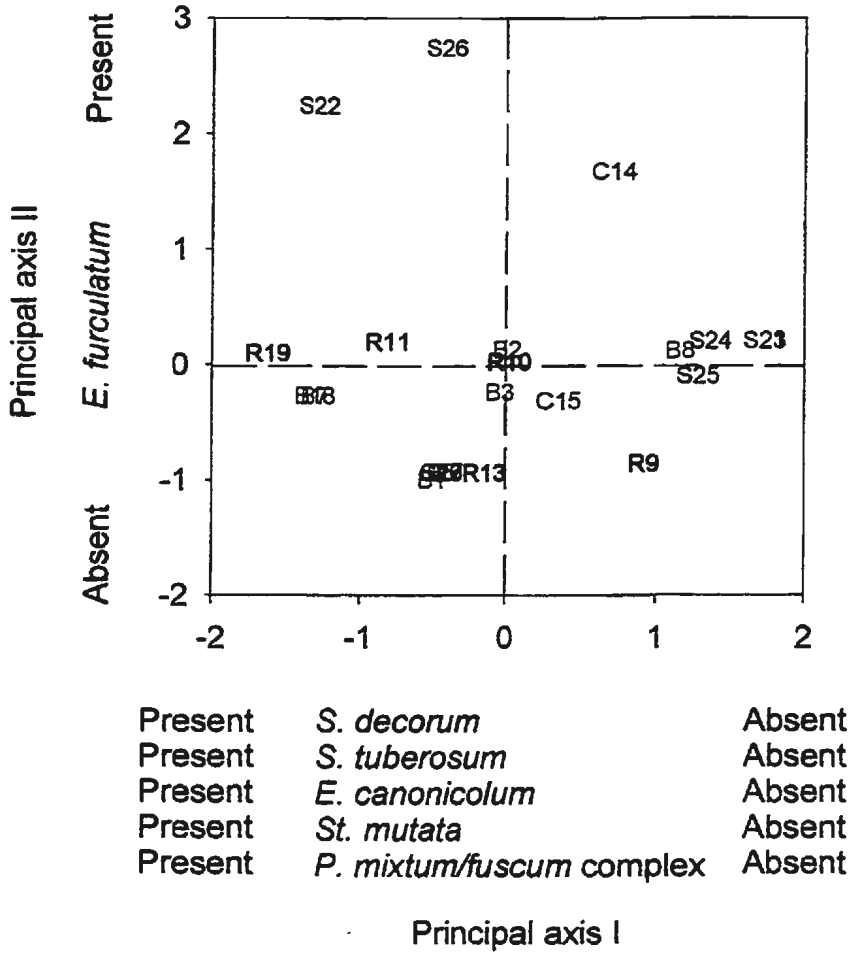


Figure 16. PCA regional and site biological results. No regional, but site separation based on inter-correlated adjusted pooled taxa richness (Presence/Absence) of simuliids. This figure reflects the data with the mis-identified taxa as noted in Tables 6 and 7.

Table 16. Principal components analysis of the adjusted pooled abundance of 11 simulild taxa from the 23 sites. Rare taxa were removed from the analysis. Pearson's correlation was used to assess significant correlations among PC-Scores and abundance data (r, $\alpha < 0.01$). The first five factors explain 80.6% of the variance within the data.

Principal axes (factors)	Simulild taxa and range of abundance values			Interpretation of PC-Axes scores		Correlation among taxa and PC-Axes scores	Percent explained variance
		Minimum	Maximum	Low score	High score		
I	*P. mixtum/fuscum* complex	0	3525	Scarce	Abundant	0.876	
I	*C. ornithophilia*	0	13566	Scarce	Abundant	0.736	
I	*S. tuberosum*	0	2091	Scarce	Abundant	0.613	
I	*S. vittatum*	0	15529	Abundant	Scarce	-0.627	22.7
II	*S. venustum/verecundum* complex	0		Scarce	Abundant	0.717	
II	*E. furculatum*	0	36	Abundant	Scarce	-0.785	
II	*E. craigi/caledonense* complex	0	1695	Abundant	Scarce	-0.793	22.4
III	*S. corbis*	0	1386	Scarce	Abundant	0.679	15.6
IV	*E. aureum*	0	121	Abundant	Scarce	-0.736	10.7
V	*S. decorum*	0	84	Abundant	Scarce	-0.855	9.2
Total							80.6

Note: The above results reflect the data with the mis-identified taxa as noted in Tables 6 and 7.

E. aureum and *S. decorum* contributed negatively to Factors IV and V respectively. Again, it should be noted that the current analysis is "an investigation of community structure and not one of taxa abundance in the traditional sense of the word". Ludwig and Reynolds (1988) refer to this type of analysis as a r-strategy ordination of community structure.

No regional separation was evident in the scatter plot of the pooled taxa abundance Principal axis I and II since the sites in a region did not group together on these two factors (Figure 17). At the site level, sites grouped over regions as similar numbers of individuals were collected from sites in all regions. On Factor I, B18, R13, and R19 were grouped together. C14, S24, and S26 were grouped together. S22 was set apart from the 23 sites. The remaining sites were grouped together. On Factor II, C14, S22, S24, and S26 were grouped together and separate from the remaining sites which themselves were grouped together. There were no distinct regional nor site patterns in the remaining taxa abundance factor scores.

3.4.4. *Pearson's correlation of the environmental and biological PCA*

The Pearson's correlation results showed four significant correlations among the environmental and biological PCA scores (Table 17). Pearson's correlation analysis was used because the PCA factors were by definition orthogonal to each

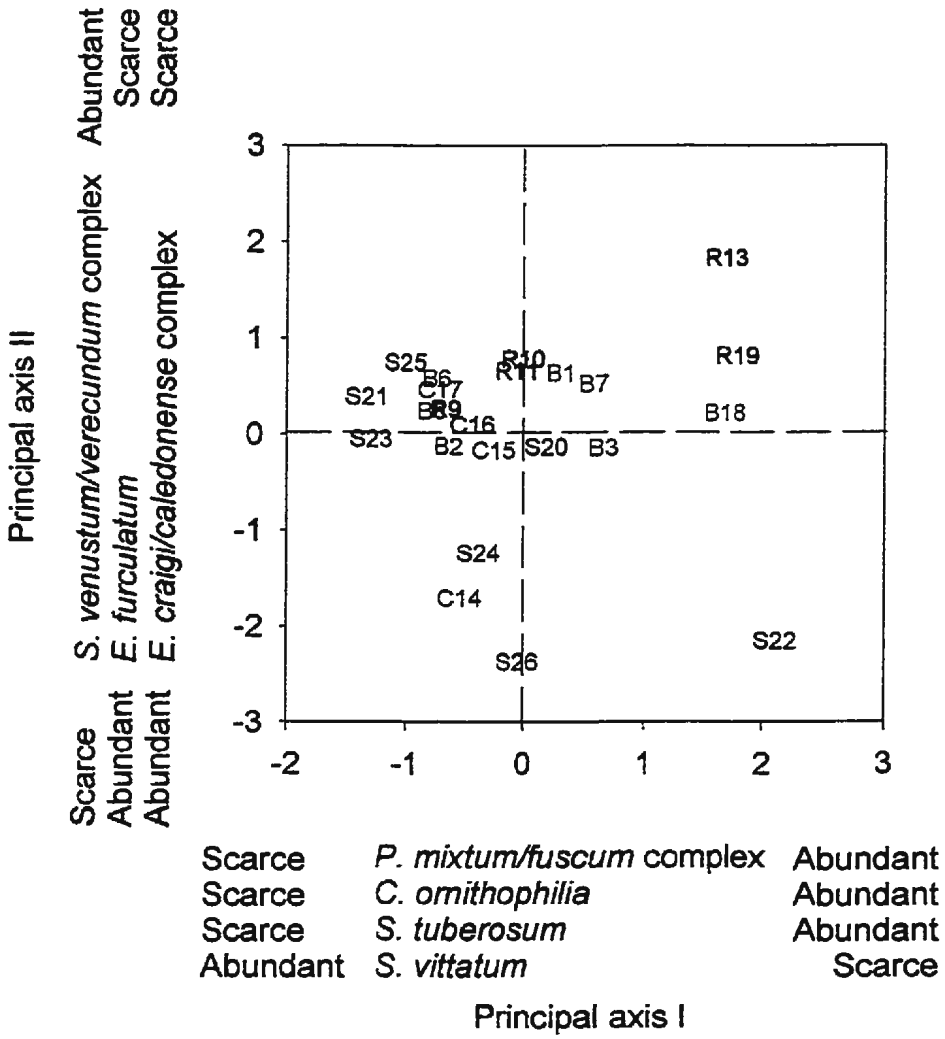


Figure 17. PCA regional and site biological results. No regional, but site separation based on inter-correlated adjusted pooled taxa abundance of simuliids. This figure reflects the data with the mis-identified taxa as noted in Tables 6 and 7.

Table 17. Pearson's correlation among PCA environmental, adjusted pooled taxa richness (Presence/Absence), and adjusted pooled taxa abundance PC factor scores with eigenvectors > 1.0. Values reported are the r, (*p*-value), and α-levels of significance.

	Environmental Factor I	Environmental Factor II	Environmental Factor III	Environmental Factor V
Presence/Absence I	ns	ns	0.568 (0.005**)	ns
Presence/Absence II	ns	ns	ns	ns
Presence/Absence III	ns	ns	ns	ns
Presence/Absence IV	ns	ns	ns	ns
Abundance I	ns	ns	-0.541 (0.008**)	ns
Abundance II	ns	0.421 (0.046*)	ns	-0.425 (0.043*)
Abundance III	ns	ns	ns	ns
Abundance IV	ns	ns	ns	ns
Abundance V	ns	ns	ns	ns

* $\alpha < 0.05$, ** $\alpha < 0.01$, and **ns** not significant

Note: The above results reflect the data with the mis-identified taxa as noted in Table 6 and 7.

other (Sokal and Rohlf 1995; J. J. H. Ciborowski, *personal communication*). Environmental Factor III (SO_4^{2-} and Cu^{2+} concentrations) was positively correlated to Presence/Absence Factor I (absence of *S. decorum*, *S. tuberosum*, *E. canonicolum*, *St. mutata*, and *P. mixtum/fuscum*) ($p = 0.005$, df = 182) (Figure 18). Environmental Factor III (SO_4^{2-} and Cu^{2+} concentrations) was negatively correlated to Abundance Factor I (abundance of *P. mixtum/fuscum*, *C. ornithophilia*, and *S. tuberosum*, and scarcity of *S. vittatum*) ($p = 0.008$, df = 458) (Figure 19A). Environmental Factor II (stream order, average current velocity, substrate, and stream width) was positively correlated to Abundance Factor II (abundance of *S. venustum/verecundum*, and scarcity of *E. furculatum* and *E. craigi/caledonense*) ($p = 0.046$, df = 458) (Figure 19B). Environmental Factor V (physical disturbance score) was negatively correlated to Abundance Factor II (abundance of *S. venustum/verecundum*, and scarcity of *E. furculatum* and *E. craigi/caledonense*) ($p = 0.043$, df = 458) (Figure 19C). These correlations suggest that combinations of environmental variables affect the simuliid assemblage, but these correlations require further testing to confirm causal relationships among the identified variables.

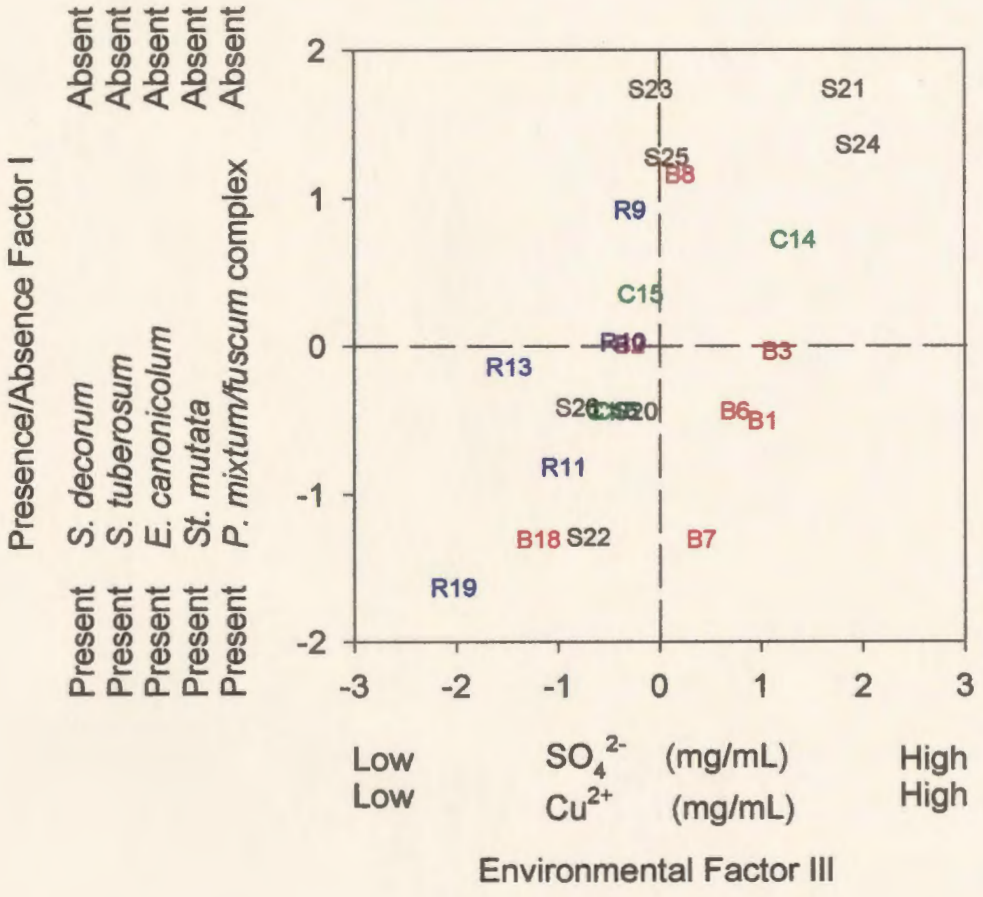
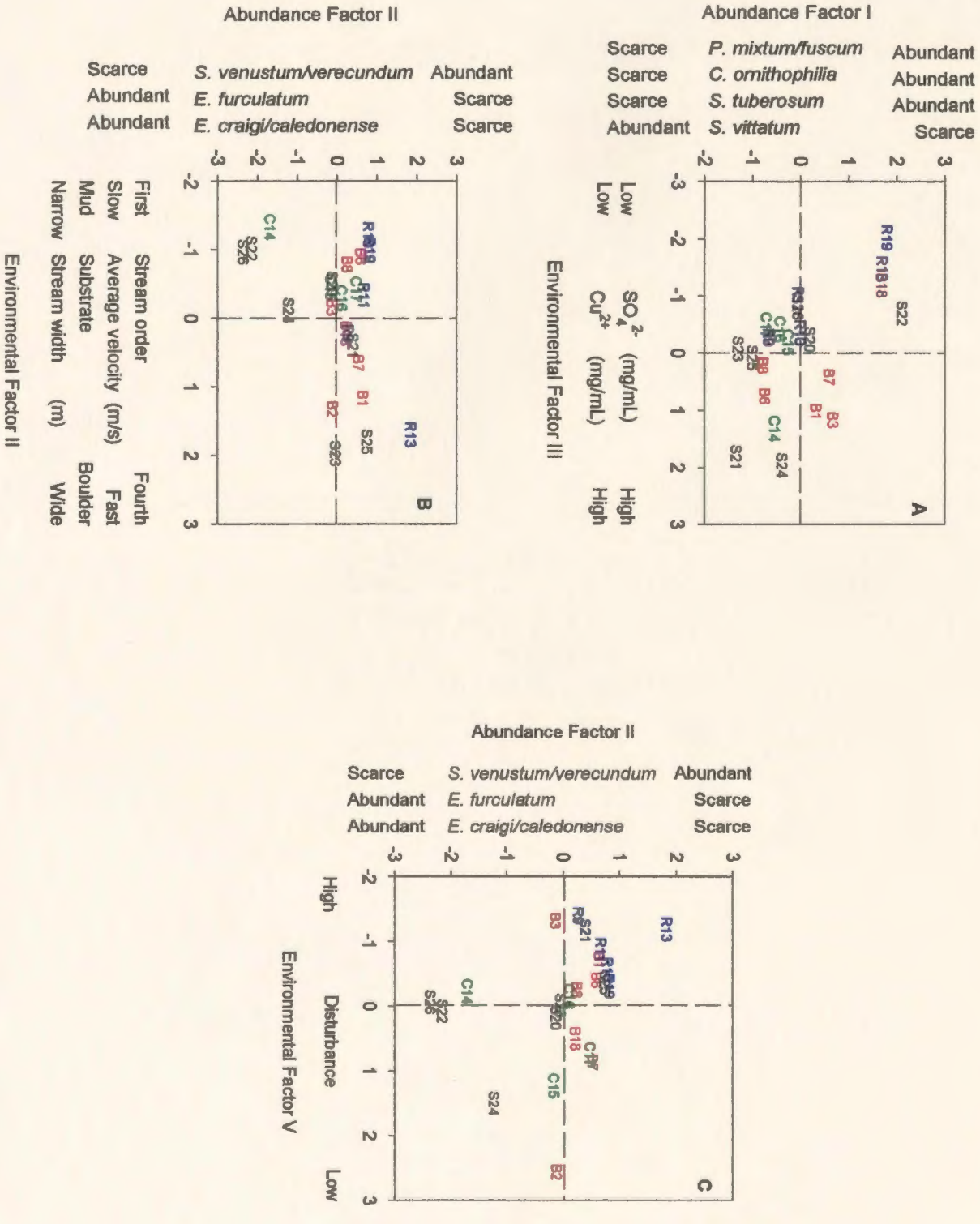


Figure 18. Pearson's correlation results among PCA Factor scores. Environmental Factor III is correlated to Presence/Absence Factor I. This figure reflects the data with the mis-identified taxa as noted in Tables 6 and 7.

Figure 19. Pearson's correlation results among PCA Factor scores. Environmental Factor III is correlated to Abundance Factor I (**A**), Environmental Factor II is correlated to Abundance Factor II (**B**), and Environmental Factor V is correlated to Abundance Factor II (**C**). These figures reflect the data with the mis-identified taxa as noted in Tables 6 and 7.


Abundance Factor I
Scarce P. mixtum/fuscum Abundant
Scarce C. ornithophilia Abundant
Scarce S. tuberosum Abundant
Abundant S. vittatum Scarce
Low SO4 2- (mg/mL) High
Low Cu2+ (mg/mL) High
Environmental Factor III
A
Abundance Factor II
Scarce S. venustum/verecundum Abundant
Abundant E. furculatum Scarce
Abundant E. craigi/caledonense Scarce
First Stream order Fourth
Slow Average velocity (m/s) Fast
Mud Substrate Boulder
Narrow Stream width (m) Wide
Environmental Factor II
B
Abundance Factor II
Scarce S. venustum/verecundum Abundant
Abundant E. furculatum Scarce
Abundant E. craigi/caledonense Scarce
High Disturbance Low
Environmental Factor V
C

4.0. DISCUSSION

Are the human communities on the Avalon and Bonavista Peninsulas having an impact on the health of 23 lake-outlet streams as reflected in changes in the measured environmental and biological data? This question is of interest because of the greater anthropogenic inputs anticipated in the watersheds of Bonavista, Random Island, and Come-by-Chance as the human communities in these regions seek alternate means of sustaining their communities after the collapse of the north Atlantic cod fishery. Therefore, this study was undertaken to assess the impacts of regional and site environmental differences, due in part to natural as well as human-induced disturbances, on the taxa richness, taxa abundance, and final-larval instar head capsule sizes of simuliids from 4 regions and 23 streams on the Avalon and Bonavista Peninsulas. The results of this study generally showed that regional and site differences in the measured environmental variables were correlated to the structure of the simuliid assemblage. The results are discussed first in a regional context, followed by a discussion on selected site differences in the environmental and biological data.

4.1. Regional Chemical and Physical Differences

The regional comparison showed statistically significant regional differences in the measured chemical variables. St. John's was expected to be different from the

other regions because it is an urban centre with greater anthropogenic inputs compared to the more rural forested and wetland locations in Bonavista, Random Island, and Come-by-Chance. The high St. John's conductivity and ion concentration values, except for SO_4^{2-}, reflect inputs from urban run-off via storm-sewers as well as surface run-off feeding into the upstream drainage systems. In contrast, Come-by-Chance is the least affected by direct run-off from disturbed upstream locations. However, it is affected by atmospheric deposition from the plume of the "dirtiest" oil refinery in Canada (M. H. Colbo, *personal communication*). The oil refinery is about 5.63 km southwest of the sample sites. This oil refinery has been linked to the atmospheric deposition of SO_4^{2-}, a major component of acid rain, and other ions into the surrounding terrestrial environment around Come-by-Chance (Wadleigh *et al.*, *unpublished data*). Through spring rains and poor soil absorption, these ions find themselves in the aquatic environment as shown by Griffiths and Keller (1992) in Sudbury, Ontario.

The ponds and outlet streams from the four regions were expected to be acidic because of the poor buffering capacity of most freshwater ponds and streams in Newfoundland (Larson and Colbo 1983, Ryan *et al.* 1993). The poor buffering capacity increases the susceptibility of the ponds and outlet streams to atmospheric acidic inputs. Come-by-Chance was expected to be the most acid of the four regions because wetlands, natural sources of humic acid, dominate its landscape. However,

Bonavista had a lower mean pH value than Come-by-Chance. This lower value for Bonavista may be due natural anthropogenic transport and deposition of SO_4^{2-} from onshore gales from the north Atlantic as well as the late snow melt period in May 1995 (M. H. Colbo, M. Wadleigh, and G. Morin (Environment Canada-New Brunswick), *personal communications*).

As a result of the low mean pH value in Bonavista, it was not surprising to measure high Al^{3+} and Cu^{2+} concentrations because acidic inputs also leach ions from the bedrock and soils through increased solubility and ion exchange with the sediment (Hall *et al.*1980, Chmielewski and Hall 1992, Dojlido and Best 1993, Hall 1994). However, low concentrations of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} were measured in Bonavista because of the lack of natural sources and direct anthropogenic inputs of these cations. This is in contrast to St. John's where these ions enter the watersheds mostly from storm sewer and surface run-offs.

There were no significant regional difference in TOS and TIS concentrations, but Random Island had marginally higher concentrations which were due to bank side erosion, beaver activity, high flow, and human activities at the outlets. This marginal difference might be biologically significant because the higher the TIS concentration, the lower the food quality available to simuliids which translates into smaller sized larvae (Colbo 1982, Morin and Peters 1988, Richardson and Mackay 1991; Perez, *unpublished data*). Furthermore, too high of a concentration of TOS

might reduce the filtering activity as the simuliids would not be filtering as often to obtain their nutritional requirements.

The regional comparison showed no statistically significant regional differences in the measured physical variables, except in the proximate cover and physical disturbance scores. The results were not a surprise because for comparative purposes, the 23 sites were selected based on their similar physical characteristics regardless of their regional location. In other words, a site in Bonavista was selected because it had similar physical characteristics to a site in St. John's. This allows for site comparisons over regions as discussed in subsequent sections.

4.2. Regional Taxa Richness and Taxa Abundance Differences

There was no statistically significant difference in pooled taxa richness among the four regions, indicating that the four regions could support a variety of simuliid taxa. However, a regional comparison showed that St. John's was biologically richer than Random Island than Bonavista than Come-by-Chance.

Taxa richness was pooled across the sampling periods because the mean values were not equal to the medians. Taxa abundance was also pooled for the same reason. This data pooling was also used in a study of benthic invertebrate assemblages in northwestern North America (Corkum and Currie 1987, Corkum

1989).

In this study, 16 taxa were morphologically identified in the four regions. This number underestimates the true richness of the simuliid assemblage because it does not consider sibling species or cytotaxa which are prevalent in the simuliid family (McCreadie and Colbo 1991). However, morphological identification was valid in the current study because the response of benthos to relatively coarse environmental gradients could be detected at the generic-, family-, and/or order-level of identification while the response to fine-scale gradients require specific-level identifications (Waterhouse and Farrell 1985). Furthermore, although simuliid sibling species tend to be differentiated by their preference for lake-outlets versus downstream locations, and small streams versus large rivers (McCreadie and Colbo 1991, 1992), this difference should not have much impact on this study because only lake-outlets were sampled.

A regional comparison showed that Random Island supported the greatest number of simuliids (or pooled taxa abundance) followed by St. John's, Bonavista, and Come-by-Chance. This difference in pooled taxa abundance was not statistically significant, indicating that the four regions could support similar numbers of simuliids. However, it is worth pointing out that the observed differences in pooled taxa abundance may be linked to the environmental conditions of a region. McCreadie and Colbo (1992) reported that taxa abundance is a function of the numbers of

ovipositing females, larval survival, immigration, and emigration. These ecological parameters may be affected by the environmental conditions of a region or a site.

4.3. Regional Head Capsule Size Differences

There were statistically and biologically significant differences in final-instar head capsule measurements. This result was not surprising because the three taxa were expected to have different sized head capsules as *S. vittatum* is usually larger than *St. mutata*, while *P. mixtum/fuscum* is the smallest of the three taxa.

There were statistically significant regional differences in the head capsule measurements, indicating that the environmental condition present in a region may have had an effect on the final-instar head capsule size. Simuliids belonging to the three taxa were generally smaller on Random Island compared to individuals from the other regions, suggesting that the environmental conditions on Random Island were less than optimal for larval development. Large *P. mixtum/fuscum* and *St. mutata* larvae were collected in St. John's, suggesting that the environmental conditions in St. John's were optimal for the development of these two taxa. It has been shown that adult size decreased with a reduction in food supply, and that only larger *S. vittatum* contributed to the next generation (Colbo and Porter 1979, 1981). Reductions in adult size have been linked to larval growth and development in sub-optimal environmental conditions (Ross and Merritt 1987). However, it must be stressed that

changes in larval size may also be linked to changes in rates of survival and development. For example, larger larvae may occur in environments where growth rate is slowed. Extended growth rates, in turn, can have a negative impact on fitness (M. H. McCreadie, *personal communication*).

These regional differences in head capsule measurements may also be due to competition and distributional patterns or may reflect genetic differences among demes. Competition in a food limited environment can be 1) inter-specific among adjacent larvae as they maximise their territory or 2) intra-specific among co-existing simuliids and other filter-feeders on the same patch of substrate (Colbo 1982). *Simulium vittatum*, through intra-specific competition, restricted *P. mixtum/fuscum* and *St. mutata* into sub-optimal habitats, and were better competitors for food and habitat resources in resource-limited conditions because of their aggressive behaviours towards neighbouring *S. vittatum* as well as other simuliid taxa and benthos (Harding and Colbo 1981, Colbo 1982, Morin *et al.* 1988, Honěk 1993). Kerans (1992) reported that these aggressive encounters were partially mediated by body size such that the larger larvae often won the confrontation and smaller larvae were found drifting in the stream. The shifts in distribution resulting from these aggressive behaviours can also affect the final-larval instar sizes (Harding and Colbo 1981). *Simulium vittatum* distribute themselves apart, whereas *P. mixtum/fuscum* tend to aggregate in clumps; *St. mutata* are less tolerant of their neighbours than

P. mixtum/fuscum, but less aggressive than *S. vittatum.* Aggregating behaviour might result in smaller larvae in resource-limited conditions because individuals in the centre of the aggregate might not receive enough food compared to the individuals in the periphery of the aggregate that encounter the seston first. Given regional differences in the environmental and biological data, are there site differences that could explain the regional observations. Further, because the three taxa are genetically distinct species, it is reasonable to expect that there would be morphological differences reflecting the genetic uniqueness of each species (J. W. McCreadie, *personal communication*).

4.4. Site Chemical and Physical Differences

The site comparison showed statistically significant site differences in the measured chemical variables. The seven St. John's sites were expected to be different from the other 16 sites because of anthropogenic inputs from the Cities of Mount Pearl and St. John's and the Town of Paradise. These inputs reflect the salt usage on the streets and parking areas, fertilisation of urban landscapes, and storm water run-offs directly feeding into the watersheds of this region. In contrast, the sites in Bonavista, on Random Island, and in Come-by-Chance were more rural and less developed, and therefore were expected to have lower conductivity and ion concentration values which were confirmed by the results of the study.

Mean conductivity values in the 22 sites were well below the 1,500 µS/cm limit suggested by Dojlido and Best (1993). Usually there is no upper limit in conductivity because there is no direct negative effect on people's health, but waters with conductivity values greater than the 1,500 µS/cm limit are not used for irrigation. Furthermore, high conductivity values reflect high ionic concentrations which are often an indication of anthropogenic inputs especially in urban centres. In this study, S24 receives much of its salt inputs from the adjacent parking areas and the three roads that form the perimeter of the pond. The other St. John's sites also receive anthropogenic inputs from run-off, but to a lesser degree than S24 and to a greater degree than the Bonavista, Random Island, and Come-by-Chance sites. C14 which was closest to the oil refinery at Come-by-Chance surprisingly had the lowest mean conductivity value. The other Come-by-Chance sites also had lower mean conductivity values compared to the sites in Bonavista and Random Island. These results were surprising given atmospheric transport and deposition of ions from the oil refinery (Wadleigh *et al.*, *unpublished data*).

Mean pH values were high in sites from St. John's and Random Island, but low in sites from Bonavista and Come-by-Chance. These results were not surprising given the cation deficient nature of the bedrock in most of Newfoundland which makes most of the ponds and streams vulnerable to acidification (Larson and Colbo 1983, Ryan *et al.* 1993). The St. John's sites had higher mean pH values because

of the ion inputs from run-off increasing the buffering capacity of these sites, and the Random Island sites were more naturally buffered than the Bonavista and Come-by-Chance sites.

Selected ions that may be toxic at higher concentrations than measured in this study or were correlated to pH were examined for differences at the site level. S21 and S23 had similar Zn^{2+} concentrations to a site 1.8 km downstream of an effluent source from a coal-fired electric generating plant in the Clinch River (Clements *et al.* 1988). This comparison showed that S21 and S23 were chemically different and disturbed compared to sites from Bonavista, Random Island, and Come-by-Chance, but that the Zn^{2+} concentrations were not toxic even though they were elevated (Dojlido and Best 1993). Similarly, Cu^{2+} concentrations among the 23 sites were quite low and comparable to a site 0.5 km upstream of the same plant in the Clinch River (Clements *et al.* 1988). This comparison showed that the 23 sites were not affected by excessively high concentrations of Cu^{2+}. B3, B7 (Bonavista), and C14 (Come-by-Chance) had relatively high concentrations of Al^{3+} which was related to the low pH at these sites, but again these concentrations were below the toxic level of 500 µg reported by Burton and Allan (1986).

The site comparison showed no statistically significant site differences in the measured physical variables. This result was not surprising because the 23 lake-outlet sites were selected from small drainage basins with similar physical

characteristics from four regions. However, closure examination of the data showed some physical differences that might be important biologically as certain taxa are known to occur at sites with specific physical characteristics. These obvious physical differences among sites were stream width, stream order, and the physical disturbance score which were functions of the level of urbanisation and development at a site.

In terms of the physical disturbance score, the St. John's sites were scored quite high because of their vicinity to roadways and houses/buildings and the presence of the railway and land-use in the immediate region. Random Island sites, although not as urbanised as St. John's sites, also had high mean physical disturbance scores because the sites were close to roadways and houses/buildings and the presence of borrow pits, beaver dams, logging in the location, and visible signs of land-use (i.e., a dairy farm). The Come-by-Chance sites were the least physically disturbed and with the least chemical inputs of the four regions. However, any activity within the watershed will have some impact on the stream benthos as "streams are a reflection of their basins" (Hynes 1970). Further, it has been shown that under extreme disturbances, there are fewer taxa and fewer individuals while moderate levels of disturbances enhances taxa richness and taxa abundance (Wallace 1990, Johnson et al. 1993).

Human communities were not the only ones changing the landscape of the freshwater systems in the four regions especially in B3, B8, and R11. These sites were dammed by beavers. Damming caused flooding and slower flowing waters particularly in B8 and R11. This change in flow regime can shift the benthos to taxa typically occurring in lentic habitats and tolerant of silty conditions (e.g., Chironomidae) (Hynes 1970, McDowell and Naiman 1986). The dams also altered the concentrations of suspended particulates in the water column which was seen in the higher mean TOS and TIS concentration on Random Island sites compared to sites from the other regions.

The major problem with the physical disturbance scoring system was that it did not differentiate between degrees of disturbance nor how long ago a particular activity had taken place at a site. For example, the presence of a beaver dam was equated to the presence of a nearby oil refinery. Clearly, the beaver dam had an immediate and localised impact on B8 and R11 whereas the impact of the oil refinery was more long term and not as immediately apparent. Similarly, the channelisation of S21 has had a more recent impact on the benthos than the channelisation of S22 which had taken place more than 20 years ago. In the case of S22, the channel had re-forested and the benthos has had sufficient time to recover from the disturbance and the site has become over grown with vegetation. In contrast, the benthos in S21 is still recovering from the disturbance. Therefore, a composite factor is not feasible

and each factor needs to be tested separately and perhaps with finer differentiation reflecting age of disturbance and its spatial extent.

4.5. Site Taxa Richness and Taxa Abundance Differences

There were statistically and biologically significant differences in the pooled taxa richness and taxa abundance among the 23 sites, indicating that some sites were richer and more abundant than other sites. S22 was the richest site with 14 taxa, two of which were present only at this site. R11 was the next richest site with 10 taxa, but none of the 10 taxa were exclusive to R11. S21, S23, and S24 were the poorest sites in terms of taxa richness. R19 was the most abundant site followed by S20, B18, and C17. Simuliids were scarce in S21 and S23.

An examination of taxa richness showed that some sites might have been more suitable for a given taxa. *Simulium venustum/verecundum* was present in all 23 sites, and thus the presence/absence or occurrence of this taxa has little value in discriminating sites. *Simulium vittatum* and *Stegopterna mutata* were present in 20 and 19 sites respectively, and thus have some site discriminating value. However, the wide occurrence of these three taxa suggests that they are generalists with a wide tolerance for different stream conditions. *Prosimulium mixtum/fuscum* and *E. craigi/caledonense* taxa are two complexes that should also have been wide ranging. However, they were restricted to small, semi-to-well-covered, slow-flowing

streams with finer substrates, indicating that the two taxa are more specialised than assumed and do have discriminating value for stream types.

Cnephia ornithophilia occurred generally in streams with a nearby scrub-forest or forest (B2, B3, B7, B18, R19, and S22). However, the relative canopy cover over the stream (Immcov) was less important as several of the sites (B1, B2, and B18) had none-to-very-little canopy cover. The female adults of this taxon require a blood meal specifically from birds for oogensis (Bennett 1960, Cupp 1981; M. H. Colbo, *personal communication*). Therefore, one would expect to find this taxon in streams which have some canopy cover and/or near a forest with a healthy bird population. However, other sites were also capable of supporting populations of *C. ornithophilia* (R10 and R11), but none were present, indicating that other factors might be involved that reduced the suitability of these two sites. The obvious factor for these two sites was the level of physical disturbance in the immediate location as R10 had fine gravel-like substrate that was washed from the upstream all-terrain-vehicle trail, and at R11, beavers were actively damming the outlet. They changed the physical characteristics of this site in July 1995, making R11 another 'pond'. The artificial substrates in R11 were re-positioned downstream in locations with outlet characteristics. This re-location could account for R11 being the richest site on Random Island as the flooding of the original outlet probably forced the simuliids downstream by drift where they encountered the transplanted artificial substrates.

Simulium corbis was present in wide, large, fast-flowing, open streams with boulder-type substrates, and a nearby forest (R13 and S25). B1 and B2 in Bonavista could have supported populations of *S. corbis* as these two sites had similar physical attributes as R13 and S25, except for the dense growth of vascular aquatic vegetation in B1 and the heavy tufa covering the boulders in B2 which were both lacking in R13 and S25. This dense algal growth and encrustation of substrates have been negatively correlated to simuliid occurrence by other studies (Colbo and Wotton 1981, Crosskey 1990).

Eusimulium aureum was present in a few coastal sites (S26 and all Random Island sites except for R9). Crosskey (1990) observed *E. aureum* almost always in tiny streams near the coast in the eastern Atlantic seaboard, and suggested that *E. aureum* was quite tolerant of salt water. *Eusimulium aureum* was not present in R9 which was further inland than the other Random Island sites. Furthermore, *Eusimulium* species are adapted to slower flowing water which could explain their presence in R11, S22, and S26. However, other ecological and environmental factors might also have prevented *Eusimulium* spp. from occurring elsewhere on the Avalon and Bonavista Peninsulas. The occurrence of the other taxa morphologically identified in this study agreed with the findings of McCreadie *et al.* (1995).

Besides examining each taxa individually, their co-occurrences were examined as taxa interactions were equally important in the stream environment.

The occurrence of taxa in a particular site is influenced by a myriad of ecological and environmental factors which are often co-dependent. This co-dependence makes it difficult to distinguish direct causal relationships. The ecological factors include: 1) drifting behaviour (Hall *et al.* 1980, Hall 1994), 2) inter- and intra-specific competition (Colbo 1979, Harding and Colbo 1981, Hemphill and Cooper 1983), and 3) female oviposition (Bass and Armitage 1987, McCreadie and Colbo 1992). Corkum and Currie (1987) succinctly stated that the "distributional patterns of organisms are controlled by dispersal mechanisms, historical factors (e.g., connecting pathways, dispersal barriers), and tolerance to environmental conditions".

Female oviposition is probably the most important ecological factor and has accounted for the enormous concentration of simuliids at lake outlets (Carlsson *et al.* 1977, Bass and Armitage 1987, McCreadie and Colbo 1992). McCreadie and Colbo (1992) stated that taxa richness or occurrence in a particular stream was largely a function of female oviposition, and lake outlets serve as visual cues for female simuliids as they seek out suitable habitat to lay their eggs. Therefore, changes in environmental variables that affect adult survival and behaviour will influence a species occurrence, indicating that non-aquatic factors can affect the occurrence of the aquatic stages.

Drifting behaviour and competition are probably the next most important ecological factors influencing taxa richness, particularly in resource limited

conditions. Simuliids locate optimal habitats where inter- and intra-specific competition is at a minimum through drifting (Morin and Peters 1988). However, in this study, drifting was probably not as important as competition because all the sites sampled were lake-outlets. Drifting behaviour is more important at downstream locations (Colbo 1979, 1982). Competition on the other hand is important because, as Morin and Peters (1988) reported, *S. vittatum*, which hatched earlier than *P. mixtum/fuscum* and *St. mutata*, displaced the larvae from the other two taxa into sub-optimal habitats through intra-specific competition.

An examination of taxa abundance showed that some sites might also have been more suitable for a given taxa. *Simulium venustum/verecundum* complex was the most abundant taxa in this study. For example, it accounted for 73.5% of the pooled abundance in R19, 98% in R9, 72.1% in R11, 40.4% in R13, and 90.5% in R10. The data suggests that R13 was a less favourable site for *S. venustum/verecundum* than R9. This result was not surprising given that there is a culvert at the outlet of R13 which might have affected female ovipositing. This taxon was also quite scarce in S21, S23, S24, and S25.

No *C. ornithophilia* was sampled from the Come-by-Chance sites. These sites are in open locations with very little scrub-forest which is in contrast to S22. S22 had the most abundant population of *C. ornithophilia* and was probably because S22 was forested and covered by a canopy which is important because it provides

habitat for forest birds which this taxon relies on for their blood meal for oogensis. B18 had about half as many *C. ornithophilia* as S22. This site had no dense canopy cover, but was near a forest. R19 was expected to have more *C. ornithophilia* than was reported because it was similar to S22 in physical characteristics. However, other factors might have reduced the numbers of *C. ornithophilia* which were not tested in this study (i.e., too few ovipositing female *C. ornithophilia* or sampling was too late to effectively assess the numbers of this taxa as the taxa emerged sooner than expected).

Simulium corbis were numerous in R13, but scarce in R9 and S25. This taxon is known to inhabit in large numbers fast-flowing, large streams (M. H. Colbo, *personal communication*). Therefore, its scarce abundance at R9 was not unexpected as R9 was a first-order stream that was narrow and open, but fast-flowing. In contrast, B2, B7, S23, and S25 were expected to have similar abundances of *S. corbis* as R13 because they were third-to-fourth-order streams that were wide, fast-flowing, and open with boulder-type substrates; physical stream characteristics favoured by *S. corbis*. However, the scarcity of this taxon in S25 might be due to water quality changes noted as a result of urbanisation compared to R13. This urbanisation effect might also be true for S23. However, the scarcity of *S. corbis* in Bonavista might be due to the exposed nature of the watershed.

The rare taxa (*E. croxtoni, E. euryadminiculum, E. excisum,* and *E. aestivum*) were not only rare because they were found in two or less sites, but also because they were few in numbers. These taxa were present in numbers in only one site (S22) which was covered by a canopy, surrounded by trees, rather narrow, and with very little submerged vascular aquatic vegetation, but with considerable emergent vegetation. The physical characteristics of the other sites might have been sufficiently different to prevent these rare taxa from exploiting those sites. For example, R19 had similar physical stream characteristics to S22 with slow water flowing through emergent sedges, then entering a forested location. However, the ponds feeding these two sites were chemically and physically different.

4.6. Site Head Capsule Size Differences

Head capsule sizes for the *P. mixtum/fuscum, S. vittatum, and St. mutata* did decrease in relation to an increase in stream size and proximity to an estuary. This size differential is related to the drainage basin size, flushing rate of the upstream pond, nutrient availability, and seasonal productivity (Colbo 1982). Headwater sites tend to be more nutrient rich than sites lower in the watershed, closest to the estuary. However, as observed in this study, there was no consistent pattern in headwater streams as some sites had larger while others smaller sized larvae, indicating that some sites were better habitats than others for the simuliids. The successive sites

lower in the watershed showed this decreasing pattern in head capsule sizes, indicating that B2, for example, is a less suitable habitat than B7 for *P. mixtum/fuscum* whose head capsules were smaller in B2 than in B7. The other two taxa showed similar decreasing patterns in the sites where they were sampled. Given the site and regional differences in the environmental and biological data, are there any significant correlations among all variables that might suggest natural or human-induced impacts.

4.7. Correlations among Environmental Variables, Taxa Richness, Taxa Abundance, and Head Capsule Size

The univariate analyses showed statistically significant correlations among the chemical environmental and biological variables measured in this study, but no correlation among the physical environmental and biological variables. These statistically significant chemical correlations indicate potential chemical effects on the simuliid assemblage in eastern Newfoundland. These correlations are important because researchers have shown that the environmental condition of a region or a site can impact on simuliid taxa richness, taxa abundance, and adult size (Colbo and Porter 1979, 1981, Amrine 1982, Colbo 1982, Armitage 1984, Corkum and Currie 1987, Ross and Merritt 1987, Morin and Peters 1988, Ciborowski and Adler 1990, Crosskey 1990, McCreadie and Colbo 1991, Chmielewski and Hall 1992, Heliövaara

and Väisänen 1993, Hall 1994, McCreadie *et al.* 1995).

There were significant negative correlations among the mean concentrations of SO_4^{2-} and K^+ and the pooled taxa richness per site, indicating that high concentrations of SO_4^{2-} and K^+ might limit the occurrence of simuliids in the current study. There were also significant negative correlations among mean concentrations of Zn^{2+} and Cu^{2+} and the pooled taxa abundance per site, indicating that high concentrations of Zn^{2+} and Cu^{2+} might limit the abundance of simuliids in the current study. The toxic effects of Zn^{2+} and Cu^{2+} were reported by Clements *et al.* (1988) as significant reductions in taxa abundance and the abundance of the dominant taxa were observed within four days of exposure to low levels of Zn^{2+} and Cu^{2+}. Furthermore, Hellawell (1986) and Heliövaara and Väisänen (1993) reported that high concentrations of Cu^{2+}, Zn^{2+}, and Al^{3+} were toxic to many macroinvertebrates; Cu^{2+} is the most toxic while Al^{3+} is the least toxic of the three ions. Additionally, K^+ is more toxic than Ca^{2+}, Mg^{2+}, and Na^+. However, the correlations in this study only imply a possible relationship among variables. What is required is an experimental evaluation of the sub-lethal effects of these ions to determine their actual impacts on simuliid richness and abundance.

There were no significant correlations among mean pH and the pooled taxa richness and taxa abundance per site. These results were not surprising given that simuliids were more acid tolerant than other stream benthos (Crosskey 1990,

Chmielewski and Hall 1992). However, acid tolerances among simuliid species are dependent on which developmental stage has been exposed to the acidic condition. Chmielewski and Hall (1992) have shown that simuliids that over-winter as larvae are less tolerant of acidic pulses associated with snow melt, and have a decrease in pupation and an increase in malformed pupae. Hall (1994) reported that low pH could: 1) directly affect the physiology of the organism, 2) indirectly affect the organism by causing an increase in the concentrations of toxic ions which have been leached out of the riparian zone and the bedrock, and 3) indirectly by reducing the quality of seston by killing the micro-fauna inhabiting the detritus. The current study did not consider the physiological nor the indirect effects of low pH since it was believed that any effects of low pH would have manifested itself as a decrease in pooled taxa richness and taxa abundance. Low pH and acidification was shown to increase the drifting behaviour of simuliids and other benthos (Hall *et al.* 1980, Hall 1994); a factor that requires testing under controlled conditions.

The multivariate analyses showed a statistically significant correlation between Environmental Factor III and Presence/Absence Factor I, indicating that high concentrations of SO_4^{2-} and Cu^{2+} together might reduce the occurrence of *S. decorum*, *S. tuberosum*, *E. canonicolum*, *St. mutata*, and *P. mixtum/fuscum*. There was also a statistically significant correlation between Environmental Factor III and Abundance Factor I, indicating that high concentrations of SO_4^{2-} and Cu^{2+}

together might also reduce the numbers of *P. mixtum/fuscum*, *C. ornithophilia*, *St. tuberosum*, and *S. vittatum*. These results were not surprising given that high Cu^{2+} concentrations were reported toxic to many macroinvertebrates (Hellawell 1986, Heliövaara and Väisänen 1993).

The univariate analyses showed no statistically significant correlations among the physical environmental variables and the pooled taxa richness per site. There were also no statistically significant correlations among the physical environmental variables and the pooled taxa abundance per site. These results were not surprising given that the richness and abundance values only considered numbers of taxa and individuals, but not the type of taxa. However, as previously discussed, certain taxa occur only in habitats with specific physical characteristics while others are less specialised, leading to significant biological correlations among the physical environmental and biological data.

The multivariate analyses showed a statistically significant correlation between Environmental Factor II and Abundance Factor II, indicating that large and wide, fast flowing streams with cobble-boulder type substrates might be unsuitable habitats for *E. furculatum* and *E. craigi/caledonense*, but suitable for *S. venustum/verecundum*. *Eusimulium* spp. appear to be specialists, restricted to small, semi-to-well-covered, slow-flowing streams with finer substrates, unlike *S. venustum/verecundum* which appear to be two generalists that occupy a range of habitat types (Lake and Burger

1983). There was also a statistically significant correlation between Environmental Factor V and Abundance Factor II, indicating that physically disturbed sites had fewer *E. furculatum* and *E. craigi/caledonense*, but more *S. venustum/verecundum* individuals. This result was not surprising given that increased physical disturbance often reduces the numbers of individuals as well as the occurrence of sensitive taxa (Culp *et al.* 1986, Clements *et al.* 1988, Resh *et al.* 1988, Wallace 1990, Rosenberg and Resh 1993, Onwubuke 1996, Lomond 1997).

There were no statistically significant correlations among mean conductivity values and pooled taxa richness and taxa abundance, even though the sites with the highest mean conductivity values had few taxa and few individuals. However, there might be a biologically significant correlation given that conductivity is also a measure of dissolved solids in the water column. A negative correlation was expected because the higher the conductivity, the higher the concentrations of dissolved solids, particularly inorganic refractory solids (or TIS) and ions, which decrease the quality of seston that simuliids feed on; hence smaller sized larvae (Amrine 1982, Wotton 1984, Morin and Peters 1988, Richardson and Mackay 1991, Onwubuke 1996).

There were significant correlations among TOS concentration and the final-larval instar head capsule sizes of *P. mixtum/fuscum, S. vittatum, and St. mutata*. There were also significant correlations among TIS concentration and sizes of the

three taxa. These results indicate that the concentrations organic and inorganic solids might affect the growth of the three taxa, particularly on Random Island where the amount of solids in the water column were the highest and composed primarily of inorganic refractory and mineral particles. These inorganic particles entered the stream through bank side erosion, human activity near the stream and natural disturbances. Higher TIS concentrations diluted the quality of the total seston which resulted in lower concentrations of high-quality food available to the larvae (Richardson and Mackay 1991). Other effects of increased TIS concentrations were the scouring of substrate surfaces which tended to dislodge simuliids from the substrates and the filling of interstitial spaces among the substrates (Armitage 1984, Culp *et al.* 1986). The negative correlation among TOS concentration and the final-larval instar sizes indicate that the final-larval instars were not efficiently filtering the higher TOS load. The TOS might have been too numerous for the simuliids to filter without clogging their cephalic fans or too small for the final-larval instars to filter at all. Wotton (1984) confirmed that different sized larvae selectively filter food particles, thereby reducing intraspecific competition since small larvae were better able to ingest particles <13 µm in diameter while larger larvae were better able to filter particles >52 µm.

Head capsule measurements of *S. vittatum*, *P.mixtum/fuscum*, and *St. mutata* were correlated to pH and Al^{3+} concentrations. Further investigation is necessary

because the effects of these chemical variables could manifest directly by affecting the physiology of the simuliids, indirectly through toxic effects of Al^{3+} retarding growth, and/or confounding effects of one or more of these variables (McCreadie and Colbo 1992, Hall 1994). Overall, the environmental conditions in the four regions and 23 sites have had some impact on the pooled taxa richness, pooled taxa abundance, and final-instar head capsule sizes of simuliids.

5.0. CONCLUSIONS

The association between anthropogenic inputs, often the result of human activity within a watershed, and the structure of the simuliid community were investigated. The environmental analyses showed statistically significant regional and site differences related to the chemical stream variables, but the approach used showed no statistically significant differences in the physical stream variables, except for proximate vegetative cover and physical disturbance scores. The site differences in St. John's were attributed to urbanisation, but the site differences in the other regions could not be associated to specific environmental variables.

Simuliids were selected for study because they have a passive filter-feeding stage which is susceptible to disturbances associated with increased human activities within a watershed and natural disturbances associated with stream processes. These relationships were investigated using 21 environmental variables correlated to pooled taxa richness, pooled taxa abundance, and final-instar head capsule size using univariate and multivariate statistical methods.

The biological analyses showed no statistically significant differences in the pooled taxa richness and pooled taxa abundance per region. However, there were statistically significant site differences in the pooled taxa richness and pooled taxa abundance. These differences were correlated to SO_4^{2-}, K^+, Zn^{2+}, and Cu^{2+} concentrations. The multivariate analyses, which statistically grouped chemical,

physical, and biological variables into composite variables, showed a negative correlation between principal components Environmental Factor III (SO_4^{2-} and Cu^{2+} ion concentrations) and Presence/Absence Factor I (absence of *Simulium decorum*, *S. tuberosum*, *Eusimulium canonicolum*, *Stegopterna mutata*, and *Prosimulium mixtum/fuscum* complex). Principal component Environmental Factor III was also negatively correlated to principal component Abundance Factor I (scarcity of *P. mixtum/fuscum* complex, *Cnephia omithophilia*, and *Simulium tuberosum*, and *Simulium vittatum*). Principal components Environmental Factor II (stream order, average velocity, substrate type, and stream width) and Environmental Factor V (physical disturbance score) were positively and negatively correlated to principal component Abundance Factor II respectively (abundance of *Simulium venustum/verecundum* complex and *E. furculatum*, and scarcity of *E. craigi/caledonense* complex). Final-larval instars of *S. vittatum* had significantly larger mean head capsules than *St. mutata* than *P. mixtum/fuscum* complex. Final-larval instars collected from sites located in the lower reaches of a watershed had smaller mean head capsules compared to final-larval instars collected from the upper reaches which were more variable in size. The pooled taxa richness, pooled taxa abundance, and final-larval instar size of simuliids were useful in detecting environmental differences among regions and sites. However, it was difficult to distinguish among regions and sites with low-to-moderate or variable environmental

conditions as in the case of Bonavista, Random Island, and Come-by-Chance.

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Appendix 1A. Presence (+) and absence ( ) of 16 simulild taxa in Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during the Spring (May 1996 and 1997) sampling periods. The taxa are listed in a decreasing order of presence (+), and the four regions and sites within regions are arranged in a decreasing order of taxa richness. Values in brackets are corrected for mis-identified taxon.

Taxa	S22	S20	S25	S26	S24	S21	S23	R11	R19	R13	R9	R10
S. venustum/verecundum complex	+	+	+	+	+	+		+	+	+	+	+
E. craigi/caledonense complex*	+	+	+	+	+			+	+	+		
S. mutata	+	+						+	+		+	+
P. mixtum/fuscum complex**	+	+						+	+	+		
S. vittatum		+	+								+	+
S. decorum	+	+	+						+			
S. tuberosum		+						+	+	+		
C. ornithophilia	+											
*E. aestivum****	+ ( )							+ ( )				
E. aureum	(+)			+				+				
E. canonicolum†	+ ( )							+ ( )				
E. excisum††	+ ( )							+ ( )				
E. furculatum	+			+								
S. corbis			+							+		
E. congareenarum¤												
E. euryadminiculum												
May 1996 pooled richness / site	10 (8)	7	5	4	2	1	0	9 (6)	6	5	3	3
May 1996 pooled richness / region	14 (11)							12 (9)				

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimullum fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 1A. (Continued)

Taxa	B18	B6	B3	B7	B1	B8	B2	C16	C17	C14	C15
S. venustum/verecundum complex	+	+	+	+	+	+	+	+	+	+	+
E. craigi/caledonense complex*	+	+	+					+	+	+	+
S. mutata	+	+	+	+	+	+		+	+		
P. mixtum/fuscum complex**	+	+	+	+	+			+			
S. vittatum	+	+		+	+	+	+	+			
S. decorum	+			+				+	+		
S. tuberosum	+	+						+	+		
C. ornithophilia	+		+								
*E. aestivum****											
E. aureum											
E. canonicolum†											
E. excisum††											
E. furculatum											
S. corbis											
E. congareenarum¤											
E. euryadminiculum											
May 1996 pooled richness / site	8	6	5	5	4	3	2	7	5	2	2
May 1996 pooled richness / site	8							7			

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simullum aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 1A. (Continued)

Taxa	S26	S20	S22	S24	S21	S23	S25	R19	R9	R10	R13	R11
S. venustum/verecundum complex		+		+				+	+	+	+	
S. mutata	+	+	+					+	+	+	+	+
S. vittatum	+	+							+	+		
P. mixtum/fuscum complex**		+	+					+	+	+	+	+
C. ornithophilia			+					+				
E. craigi/caledonense complex*	+			+				+				
S. tuberosum								+				
S. corbis									+		+	
E. aureum												
E. canonicolum†	+ ( )											
E. euryadminiculum			+									
E. furculatum												
S. decorum	+											
*E. aestivum****												
E. congareenarum¤												
E. excisum††												
May 1997 pooled richness / site	5 (4)	4	4	2	0	0	0	6	5	4	4	2
May 1997 pooled richness / region				9 (8)						8		

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 1A. (Continued)

Taxa	B1	B7	B2	B3	B18	B8	B6	C16	C17	C14	C15
S. venustum/verecundum complex	+	+	+	+	+	+		+	+	+	+
S. mutata	+	+	+	+	+	+		+	+		
S. vittatum	+	+	+	+	+	+	+	+	+	+	+
P. mixtum/fuscum complex**	+	+	+	+	+			+	+		
C. ornithophilia	+	+	+	+	+						
E. craigi/caledonense complex*								+	+	+	+
S. tuberosum	+	+									
S. corbis											
E. aureum			+								
E. canonicolum†											
E. euryadminiculum											
E. furculatum										+	
S. decorum											
*E. aestivum****											
E. congareenarum¤										(+)	
E. excisum††											
May 1997 pooled richness / site	6	6	6	5	5	3	1	5	5	4 (5)	3
May 1997 pooled richness / region	7							6 (7)			

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 1B. Presence (+) and absence ( ) of 16 simuliid taxa in Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during the Summer (July 1995 and 1996) sampling periods. Sites B18, R19, and S20 through S26 (**) were added after the July 1995 sampling period. No taxa were collected from R13 (*) during the July 1995 sampling period because the artificial samplers were washed away during a spring storm. The taxa are listed in a decreasing order of presence (+), and the four regions and sites within regions are arranged in a decreasing order of taxa richness. Values in brackets are corrected for mis-identified taxon.

Taxa	R11	R10	R9	R13*	R19**	B7	B1	B2	B3	B6	B8	B18**
S. venustum/verecundum complex	+	+	+			+	+	+	+	+	+	
S. vittatum	+	+	+			+	+	+	+			
E. aureum	+											
S. decorum		+										
St. mutata						+						
C. ornithophilia												
P. mixtum/fuscum complex**												
*E. aestivum****												
E. canonicolum†												
E. craigi/caledonense complex*												
E. croxtoni												
E. euryadminiculum												
E. excisum††												
E. furculatum												
S. corbis												
S. tuberosum												
July 1995 pooled richness / site	3	3	2			3	2	2	2	1	1	
July 1995 pooled richness / region			4						3			

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11 in Appendix 1A.

Appendix 1B. (Continued)

Taxa	C14	C15	C16	C17	S20** S21** S22** S23** S24** S25** S26**
S. venustum/verecundum complex	+	+	+	+	
S. vittatum	+	+	+	+	
E. aureum	+				
S. decorum					
St. mutata					
C. ornithophilia					
P. mixtum/fuscum complex**					
*E. aestivum****					
E. canonicolum†					
E. craigi/caledonense complex*					
E. croxtoni					
E. euryadminiculum					
E. excisum††					
E. furculatum					
S. corbis					
S. tuberosum					
July 1995 pooled richness / site	3	2	2	2	
July 1995 pooled richness / region	3				

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11 in Appendix 1A.

Appendix 1B. (Continued)

Taxa	S22	S26	S25	S20	S21	S23	S24	R19	R13	R10	R11	R9
S. venustum/verecundum complex	+		+	+	+	+	+	+	+	+	+	+
S. vittatum	+	+	+	+	+	+				+	+	+
E. craigi/caledonense complex*	+	+	+	+			+	+				
S. decorum			+					+		+		
E. aureum	+							+	+	+	+	
E. canonicolum†	+ ( )	+ ( )						+ ( )				
St. mutata	+			+				+				+
P. mixtum/fuscum complex**	+							+	+			
C. ornithophilia	+							+				
E. euryadminiculum	+	+										
E. croxtoni	+											
E. furculatum		+										
S. corbis									+			
S. tuberosum									+			
*E. aestivum****												
E. excisum††												
July 1996 pooled richness / site	10 (9)	5 (4)	4	4	2	2	2	8 (7)	5	4	3	3
July 1996 pooled richness / region	12 (11)							11 (10)				

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11 in Appendix 1A.

Appendix 1B. (Continued)

Taxa	B18	B7	B3	B1	B6	B8	B2	C17	C16	C15	C14
S. venustum/verecundum complex	+	+	+	+	+	+		+	+	+	+
S. vittatum	+	+	+	+	+		+	+	+	+	
E. craigi/caledonense complex*	(+)	+	+					+			
S. decorum				+	+				+		
E. aureum											
E. canonicolum†	+ ( )	+ ( )									
St. mutata	+										
P. mixtum/fuscum complex**	+										
C. ornithophilia											
E. euryadminiculum											
E. croxtoni											
E. furculatum											
S. corbis											
S. tuberosum											
*E. aestivum****											
E. excisum††											
July 1996 pooled richness / site	5	4 (3)	3	3	2	1	1	3	3	2	1
July 1996 pooled richness / region	7 (6)							4			

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11 in Appendix 1A.

Appendix 2A. Abundance of 16 simuliid taxa in Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during the Spring (May 1996 and 1997) sampling periods. Percentages are in brackets and the simuliid taxa are listed in a decreasing order of abundance for the four areas and sites within areas. Values in [ ] are corrected for mis-identified taxon.

Taxa	R19		R13		R9		R11		R10	
S. venustum/verecundum complex	52119	(96)	674	(39)	1410	(99)	781	(90)	10	(83)
S. vittatum	0	(0)	0	(0)	10	(1)	0	(0)	1	(8)
P. mixtum/fuscum complex**	363	(1)	59	(3)	0	(0)	17	(2)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	16	(0)	1	(0)	0	(0)	19 [20]	(2) [2]	0	(0)
St. mutata	1150	(2)	0	(0)	7	(0)	30	(3)	1	(8)
S. tuberosum	765	(1)	334	(19)	0	(0)	6	(1)	0	(0)
S. corbis	0	(0)	664	(38)	0	(0)	0	(0)	0	(0)
S. decorum	37	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	1 [0]	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	1 [0]	(0) [0]	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	10 [0]	(1) [0]	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	4 [15]	(0) [1]	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1996 pooled abundance / site	54450		1733		1427		869		12	
May 1996 pooled abundance / region	58490									

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	S20		S22		S26		S25		S24		S21		S23	
S. venustum/verecundum complex	44619	(97)	507	(6)	38	(3)	270	(96)	85	(84)	11	(100)	0	(0)
S. vittatum	68	(0)	0	(0)	0	(0)	5	(2)	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	352	(1)	2035	(24)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
C. ornithophilia	0	(0)	4090	(48)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	465	(1)	1443 [1537]	(17) [18]	1145	(95)	1	(0)	16	(16)	0	(0)	0	(0)
St. mutata	473	(1)	229	(3)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	7	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	3	(1)	0	(0)	0	(0)	0	(0)
S. decorum	7	(0)	7	(0)	0	(0)	1	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	60 [0]	(1) [0]	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	30	(0)	15	(1)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	34 [0]	(0) [0]	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	8 [0]	(0) [0]	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0 [8]	(0) [0]	6	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1996 pooled abundance / site	45990		8445		1204		280		101		11		0	
May 1996 pooled abundance / region	56031													

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	C17		C15		C16		C14	
S. venustum/verecundum complex	29120	(99)	12708	(100)	7685	(95)	10	(43)
S. vittatum	0	(0)	0	(0)	98	(1)	0	(0)
P. mixtum/fuscum complex**	0	(0)	0	(0)	12	(0)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	25	(0)	37	(0)	117	(1)	13	(57)
St. mutata	8	(0)	0	(0)	117	(1)	0	(0)
S. tuberosum	126	(0)	0	(0)	4	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	60	(0)	0	(0)	67	(1)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)
May 1996 pooled abundance / site	29339		12745		8101		23	
May 1996 pooled abundance / region	50208							

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	B18		B2		B7		B1		B6		B3		B8	
S. venustum/verecundum complex	14432	(76)	889	(8)	1564	(70)	345	(49)	111	(94)	105	(92)	8	(17)
S. vittatum	436	(2)	9709	(92)	436	(20)	345	(49)	1	(1)	0	(0)	36	(77)
P. mixtum/fuscum complex**	2473	(13)	0	(0)	9	(0)	3	(0)	2	(2)	2	(2)	0	(0)
C. ornithophilia	548	(3)	0	(0)	0	(0)	0	(0)	0	(0)	1	(1)	0	(0)
E. craigi/caledonense complex*	94	(0)	0	(0)	0	(0)	0	(0)	1	(1)	5	(4)	0	(0)
St. mutata	990	(5)	0	(0)	150	(7)	5	(1)	2	(2)	1	(1)	3	(6)
S. tuberosum	34	(0)	0	(0)	0	(0)	0	(0)	1	(1)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	17	(0)	0	(0)	66	(3)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1996 pooled abundance / site	19024		10598		2225		698		118		114		47	
May 1996 pooled abundance / region	32824													

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense.*
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense.*
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	R19		R13		R9		R10		R11	
St. mutata	16221	(86)	5	(1)	176	(79)	137	(80)	127	(95)
C. ornithophilia	53	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. venustum/verecundum complex	376	(2)	1	(0)	26	(12)	31	(18)	0	(0)
P. mixtum/fuscum complex**	851	(5)	5	(1)	7	(3)	2	(1)	7	(5)
S. vittatum	0	(0)	0	(0)	13	(6)	2	(1)	0	(0)
E. craigi/caledonense complex*	38	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	1326	(7)	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	722	(98)	1	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1997 pooled abundance / site	18864		733		223		172		134	
May 1997 pooled abundance / region	20126									

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- **** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	B18		B7		B2		B3		B1		B8		B6	
St. mutata	5261	(40)	959	(39)	754	(36)	14	(10)	9	(9)	22	(71)	0	(0)
C. ornithophilia	4688	(36)	19	(1)	7	(0)	1	(1)	17	(17)	0	(0)	0	(0)
S. venustum/verecundum complex	2003	(15)	905	(37)	274	(13)	6	(4)	39	(40)	2	(6)	0	(0)
P. mixtum/fuscum complex**	1044	(8)	164	(7)	7	(0)	120	(82)	19	(19)	0	(0)	0	(0)
S. vittatum	144	(1)	386	(16)	1054	(50)	6	(4)	12	(12)	7	(23)	1	(100)
E. craigi/caledonense complex*	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	28	(1)	0	(0)	0	(0)	2	(2)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	15	(1)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1997 pooled abundance / site	13140		2461		2112		147		98		31		1	
May 1997 pooled abundance / region	17990													

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	C16		C15		C17		C14	
St. mutata	843	(32)	0	(0)	6	(11)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)
S. venustum/verecundum complex	1072	(41)	368	(83)	40	(71)	3	(13)
P. mixtum/fuscum complex**	15	(1)	0	(0)	1	(2)	0	(0)
S. vittatum	530	(20)	2	(0)	8	(14)	2	(9)
E. craigi/caledonense complex*	142	(5)	74	(17)	1	(2)	17	(74)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	1	(4)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	2	(8)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum***	0	(0)	0	(0)	0	(0)	0	(0)
May 1997 pooled abundance / site	2602		444		56		25	
May 1997 pooled abundance / region	3127							

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2A. (Continued)

Taxa	S22		S20		S24		S26		S21		S23		S25	
St. mutata	243	(2)	2063	(91)	0	(0)	5	(1)	0	(0)	0	(0)	0	(0)
C. ornithophilia	9437	(91)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. venustum/verecundum complex	0	(0)	49	(2)	39	(5)	0	(0)	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	618	(6)	66	(3)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. vittatum	0	(0)	99	(4)	0	(0)	1	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	0	(0)	0	(0)	747	(95)	475 [476]	(98) [98]	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	48	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	0	(0)	4	(1)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	1 [0]	(0) [0]	0	(0)	0	(0)	0	(0)
E. congareenarum¤	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
May 1997 pooled abundance / site	10345		2276		786		486		0		0		0	
May 1997 pooled abundance / region	13893													

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.
- ¤ voucher specimens identified by P. H. Adler as *Simulium congareenarum* or *Simulium anatinum*, but difficult to distinguish apart based on morphological characteristics.

Appendix 2B. Abundance of 16 simuliid taxa in Bonavista (B), Random Island (R), Come-by-Chance (C), and St. John's (S) during the Summer (July 1995 and 1996) sampling periods. Percentages are in brackets and the simuliid taxa are listed in a decreasing order of abundance for the four regions and sites within regions. Sites B18, R19, and S20 through S26 were added after the July 1995 sampling period. No taxa were collected from R13 during the July 1995 sampling period because the artificial samplers were washed away during a spring storm. Values in [ ] are corrected for mis-identified taxon.

Taxa	B2		B7		B1		B3		B6		B8		B18**
S. venustum/verecundum complex	143	(9)	809	(61)	389	(68)	241	(98)	103	(90)	96	(85)	
S. vittatum	1462	(91)	503	(38)	184	(32)	6	(2)	11	(10)	17	(15)	
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
S. decorum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
St. mutata	0	(0)	8	(1)	0	(0)	0	(0)	0	(0)	0	(0)	
E. craigi/caledonense complex*	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
E. croxtoni	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
*E. aestivum***	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
P. mixtum/fuscum complex**	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	
July 1995 pooled abundance / site	1605		1320		573		247		114		113		
July 1995 pooled abundance / region	3972												

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	R9		R10		R11		R13*	R19**
S. venustum/verecundum complex	1733	(97)	395	(97)	12	(11)		
S. vittatum	59	(3)	10	(3)	19	(18)		
E. aureum	0	(0)	0	(0)	40	(37)		
S. decorum	0	(0)	1	(0)	36	(34)		
St. mutata	0	(0)	0	(0)	0	(0)		
E. craigi/caledonense complex[*]	0	(0)	0	(0)	0	(0)		
E. croxtoni	0	(0)	0	(0)	0	(0)		
E. canonicolum[†]	0	(0)	0	(0)	0	(0)		
E. excisum[††]	0	(0)	0	(0)	0	(0)		
E. furculatum	0	(0)	0	(0)	0	(0)		
S. corbis	0	(0)	0	(0)	0	(0)		
E. aestivum[***]	0	(0)	0	(0)	0	(0)		
S. tuberosum	0	(0)	0	(0)	0	(0)		
P. mixtum/fuscum complex[**]	0	(0)	0	(0)	0	(0)		
C. ornithophilia	0	(0)	0	(0)	0	(0)		
E. euryadminiculum	0	(0)	0	(0)	0	(0)		
July 1995 pooled abundance / site	1792		406		107			
July 1995 pooled abundance / region	2305							

Notes:
[*] voucher specimens identified by P. H. Adler as *Simulium caledonense*.
[**] *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
[***] voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
[†] voucher specimens identified by P. H. Adler as *S. caledonense*.
[††] voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	C17		C15		C16		C14	
S. venustum/verecundum complex	837	(99)	362	(98)	268	(97)	13	(62)
S. vittatum	12	(1)	8	(2)	7	(3)	6	(29)
E. aureum	0	(0)	0	(0)	0	(0)	2	(10)
S. decorum	0	(0)	0	(0)	0	(0)	0	(0)
St. mutata	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	0	(0)	0	(0)	0	(0)	0	(0)
E. croxtoni	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum***	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	0	(0)	0	(0)	0	(0)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)
July 1995 pooled abundance / site	849		370		275		21	
July 1995 pooled abundance / region	1515							

Notes:
- * voucher specimens identified by P. H. Adler as *Simulium caledonense*.
- ** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadle, but can only be confirmed cytologically and therefore, reported at the complex level.
- *** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
- † voucher specimens identified by P. H. Adler as *S. caledonense*.
- †† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	S20**	S21**	S22**	S23**	S24**	S25**	S26**
S. venustum/verecundum complex							
S. vittatum							
E. aureum							
S. decorum							
St. mutata							
E. craigi/caledonense complex*							
E. croxtoni							
E. canonicolum†							
E. excisum††							
E. furculatum							
S. corbis							
*E. aestivum****							
S. tuberosum							
P. mixtum/fuscum complex**							
C. ornithophilia							
E. euryadminiculum							
July 1995 pooled abundance / site							
July 1995 pooled abundance / region							

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	B7		B2		B6		B18		B1		B3		B8	
S. venustum/verecundum complex	901	(23)	0	(0)	2559	(85)	2011	(97)	373	(39)	79	(93)	7	(100)
S. vittatum	2915	(76)	3304	(100)	437	(15)	44	(2)	588	(61)	2	(2)	0	(0)
S. mutata	0	(0)	0	(0)	0	(0)	7	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	23 [27]	(1) [1]	0	(0)	0	(0)	0 [7]	(0) [0]	0	(0)	4	(5)	0	(0)
E. croxtoni	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	8	(0)	0	(0)	6	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	4 [0]	(0) [0]	0	(0)	0	(0)	7 [0]	(0) [0]	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	0	(0)	0	(0)	0	(0)	7	(0)	0	(0)	0	(0)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
July 1996 pooled abundance / site	3842		3304		3004		2077		967		85		7	
July 1996 pooled abundance / region	13286													

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
** *Prosimulium fuscum* probably not present in Newfoundland according to J. W. McCreadie, but can only be confirmed cytologically and therefore, reported at the complex level.
*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	R9		R11		R19		R10		R13	
S. venustum/verecundum complex	14356	(99)	7746	(72)	6488	(94)	1642	(96)	583	90
S. vittatum	75	(1)	2922	(27)	0	(0)	28	(2)	0	(0)
S. mutata	15	(0)	0	(0)	217	(3)	0	(0)	0	(0)
E. aureum	0	(0)	66	(1)	121	(2)	27	(2)	2	(0)
E. craigi/caledonense complex*	0	(0)	0	(0)	11 [19]	(0) [0]	0	(0)	0	(0)
E. croxtoni	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	21	(0)	10	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	56	(9)
E. canonicolum†	0	(0)	0	(0)	8 [0]	(0) [0]	0	(0)	0	(0)
P. mixtum/fuscum complex**	0	(0)	0	(0)	22	(0)	0	(0)	2	(0)
C. ornithophilia	0	(0)	0	(0)	11	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)	7	(1)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
July 1996 pooled abundance / site	14446		10733		6900		1706		650	
July 1996 pooled abundance / region	34436									

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
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*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	C16		C15		C17		C14	
S. venustum/verecundum complex	3571	(86)	1034	(96)	569	(54)	1	(100)
S. vittatum	566	(14)	38	(4)	477	(45)	0	(0)
S. mutata	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	0	(0)	0	(0)	3	(0)	0	(0)
E. croxtoni	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	17	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	0	(0)	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	0	(0)	0	(0)	0	(0)	0	(0)
C. ornithophilia	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	0	(0)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)
July 1996 pooled abundance / site	4154		1072		1050		1	
July 1996 pooled abundance / region	6276							

Notes:
* voucher specimens identified by P. H. Adler as *Simulium caledonense*.
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*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.

Appendix 2B. (Continued)

Taxa	S22		S20		S25		S26		S21		S23		S24	
S. venustum/verecundum complex	7	(3)	151	(95)	21	(15)	0	(0)	11	(55)	2	(13)	2	(67)
S. vittatum	1	(0)	2	(1)	121	(84)	2	(2)	9	(45)	14	(88)	0	(0)
S. mutata	2	(1)	3	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. aureum	1	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. craigi/caledonense complex*	12 [47]	(5) [20]	3	(2)	1	(1)	75 [76]	(74) [74]	0	(0)	0	(0)	1	(33)
E. croxtoni	114	(48)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. decorum	0	(0)	0	(0)	1	(0)	0	(0)	0	(0)	0	(0)	0	(0)
S. corbis	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. canonicolum†	35 [0]	(15) [0]	0	(0)	0	(0)	1 [0]	(1) [0]	0	(0)	0	(0)	0	(0)
P. mixtum/fuscum complex**	21	(9)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
C. ornithophilia	39	(16)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. furculatum	0	(0)	0	(0)	0	(0)	21	(21)	0	(0)	0	(0)	0	(0)
E. euryadminiculum	7	(3)	0	(0)	0	(0)	3	(3)	0	(0)	0	(0)	0	(0)
S. tuberosum	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
E. excisum††	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
*E. aestivum****	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
July 1996 pooled abundance / site	239		159		144		102		20		16		3	
July 1996 pooled abundance / region	683													

Notes:
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*** voucher specimens identified by P. H. Adler as *Simulium aureum* complex. Cytological analysis is required to establish whether the specimens are *S. aureum* 'C' or *S. aureum* 'D' cytotypes.
† voucher specimens identified by P. H. Adler as *S. caledonense*.
†† voucher specimens identified by P. H. Adler as *S. caledonense* for S22 and *S. aureum* for R11.